Forestry-Drinking Water Quality Interactions: Final Workshop Report

Cowichan Lake Research Station
7060 Forestry Road
Mesachie Lake, B.C. V0R 2N0

March 2-3, 1993

Prepared for

Water Quality Branch
Ministry of Environment, Lands and Parks

and

Research Branch
Ministry of Forests

by

Trent Berry
Tim Webb

ESSA Environmental and Social Systems Analysts Ltd.
3rd Floor, 1765 West 8th Avenue
Vancouver, B.C. V6J 5C6

and

Chris Perrin

Limnotek Research & Development Inc.
4035 West 14th Avenue
Vancouver, B.C. V6R 2X3

Funding for this workshop was provided by the Crown Resource Inventory Initiative (CRII)

Citation: **Berry, Trent, Tim Webb and Chris Perrin 1993.** Forestry - Drinking Water Quality Interactions Workshop Report. Working report prepared by ESSA Ltd., Vancouver, B.C. for the Water Quality Branch, Ministry of Environment, Lands and Parks, and Research Branch, BC Ministry of Forests, Victoria, B.C.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any for or by any means, electronic, mechanical, photocopying, recording, or otherwise, without acknowledgement of the source of the information being given.

Table of Contents

1.0 Introduction 1

2.0 Workshop Goals and Objectives 3

3.0 Opening Plenary: Major Issues 5
- 3.1 Forest Hydrology - Dave Toews, MoF 5
- 3.2 Sediment - Pierre Beaudry, MoF 5
- 3.3 Chemistry - Rick Nordin, MELP 7
- 3.4 Health - Barry Willoughby, MoH 7
- 3.5 Limnology and Remedial Measures for Taste and Odour Problems in Capilano and Seymour Reservoirs - Chris Perrin, Limnotech Research and Development Inc. 8
- 3.6 Models - Tim Webb, ESSA Ltd. 9
  - 3.6.1 Conceptual Models 9
  - 3.6.2 Simulation Models 10

4.0 Needs/Users Discussion 11
- 4.1 Context 11
- 4.2 Needs/Priorities 11

5.0 Subgroup Summaries 15
- 5.1 Sediment Subgroup - Facilitator: Tim Webb, ESSA Ltd. 15
  - 5.1.1 Impact Hypotheses 15
  - 5.1.2 Synthesizing Current Experience and Understanding 16
  - 5.1.3 Types of Models and their Application 17
  - 5.1.4 Monitoring 19
  - 5.1.5 Additions to Guidelines and the Decision Making Process 21
  - 5.1.6 Education 21
  - 5.1.7 Recommendations 22
- 5.2 Chemistry Subgroup- Facilitator: Chris Perrin, Limnotech Research & Development Inc. 23
  - 5.2.1 Introduction 23
  - 5.2.2 Spatial Scope 25
  - 5.2.3 Conceptual Model 26
  - 5.2.4 Data Sources and Gaps 34
- 5.3 Health - Facilitator: Trent Berry, ESSA Ltd. 35
  - 5.3.1 Impact Hypotheses 36
  - 5.3.2 Research/monitoring/modelling priorities 44

6.0 Final Plenary: Where do we go from here? 49
- 6.1 Information Exchange/Inter-Agency Interaction 49
- 6.2 Research 50
- 6.3 Workshop Follow-up 50

105-03670/

7.0 General Recommendations and Directions 53

8.0 Background Literature 58

Appendix A Agenda 67

Appendix B Workshop Participants 69

Appendix C Case Study: An Integrated Watershed Management Planning Process on Eastern Vancouver Island 73

Appendix D The Status of Integrated Watershed Management Plans (IWMP's) 79

Appendix E A Summary of Community Water Supply Monitoring - FY 92/93 81

Appendix F Sediment Budget Studies in the Prince Rupert Forest Region 83

Appendix G Ministry of Health Giardia Program 99

List of Figures

1 Framework used to describe the relationship between forest management activities or stressors and chemical water quality. 27

2 Summary of the direct and indirect effects of logging activities in community watersheds on drinking water quality and ultimately human health. 37

3 Selected direct effects of forestry activities on drinking water quality. 38

4 Indirect effects of logging on drinking water quality via effects on public access to community watersheds. 42

5 Indirect effects of logging on drinking water quality via grazing activities in community watersheds. 43

6 Indirect effects of logging and recreational access in community watersheds on drinking water quality via wildlife. 45

List of Tables

1 Listing of watershed activities, variables with which the activity can be measured, and variables that potentially determine the degree of effect by the watershed activity on water chemistry. 29

2 Independent variables controlling effects of two or more potential stressors. 31

3 Endpoint variables stratified by aesthetics and health showing association with forest management activities. 33

1.0 Introduction

Resource development in community watersheds often conflicts with the objective of supplying safe, clean or adequate supplies of drinking water. Forestry-related activities such as road-building, harvesting, site preparation and other silvicultural prescriptions, have all been demonstrated in certain circumstances to affect stream hydrology, and sediment or chemical outputs from forested watersheds. Both forestry and associated activities such as recreation or grazing on forest lands may also increase the risks of microbiological contamination of drinking water. The actual pathways for these impacts are complex and their cumulative effects very difficult to assess or manage, both pre- and post-disturbance. Evaluation and management are further complicated by the involvement of multiple jurisdictions and agencies.

Growing public awareness and increased conflicts among resource users in community watersheds are placing greater demands on management, both within and among the responsible agencies.[1] There is an acute need to share the growing knowledge base about forestry-drinking water quality interactions, as well as widen that knowledge base, emphasizing issues and information especially relevant to B.C. Furthermore, a common direction and a set of analytical tools is required in order to increase co-operation among agencies and achieve the most efficient allocation of resources to address this issue.

Recognizing these needs, the Water Quality Branch of the Ministry of Environment, Lands and Parks and the Research Branch of the Ministry of Forests co-sponsored a two-day workshop at Cowichan Lake Forest Research Station, March 2-3, 1993. The twenty-five workshop participants included representatives from the Ministry of Forests, the Ministry of Environment, Lands and Parks, the Ministry of Health, two water districts (Greater Vancouver and Greater Victoria), academia, and industry (see Appendix B for a list of participants). The main goal of the workshop was to stimulate inter-agency communication and to assess the feasibility of developing analytical tools to assist in the assessment and management of forestry-drinking water quality interactions. The following report summarizes workshop discussions and makes recommendations regarding future directions for inter-agency co-operation on this important issue.

---

[1]A brief case study of the differing perspectives/conflicts of watershed users is provided in Appendix C of the report.

2.0 Workshop Goals and Objectives

The workshop was seen as the beginning of a long-term process to develop analytical tools which support evaluation and integrated management in community watersheds. Given the limits of time and size, this workshop necessarily focused on the first in a series of steps in developing analytical tools - namely problem definition and bounding, and the formulation of impact hypotheses. Impact hypotheses are explicit statements of assumed cause-effect relationships between watershed activities and drinking water quality via important processes and pathways. They are based on our best and most current understanding of the problem. While concern has been expressed about many types of activities in community watersheds, this workshop focused on forestry-related activities. In the future, the same process may be used to address concerns regarding other activities in community watersheds such as agriculture and urban or rural development.

Specific objectives of the workshop included:

- To bring together the agencies/individuals concerned with evaluating and managing the effects of forestry-related activities on water quality in community watersheds in B.C. in order to exchange information and perspectives

- To explore potential analytical tools which would support management of community watersheds, identifying potential users of those tools and their needs

- To identify priorities and recommendations for research, modelling, and inter-agency co-operation

A workshop agenda is provided in Appendix A.

3.0 Opening Plenary: Major Issues

The workshop opened with a series of presentations which were intended to provide overviews of the major issues/concerns regarding the effects of forestry activities in community watersheds on drinking water quality.

3.1 Forest Hydrology - Dave Toews, MoF

There are important differences in the hydrologic response of interior and coastal forests to forestry activities. The hydrology of interior watersheds is snow-dominated, with the hydrograph peaks generally occurring between April and early June. Coastal areas are rain dominated, exhibiting a number of peaks in the hydrograph during the fall and winter in response to major storms. The runoff is as much as an order of magnitude greater in coastal than in interior watersheds. There are also watersheds that are a hybrid of coastal and interior watersheds.

In rain dominated watersheds on the coast, forest cover removal has little affect on storm runoff because the storm season soil saturation is mainly unchanged.

In the snow dominated interior runoff harvesting can be considerably altered by forest cover removal because of changes in snow accumulation and melt. More snow tends to accumulate in clearcuts than under the surrounding canopy due to the reduction in interception losses (e.g. sublimation). Melt of this larger snowpack also tends to be quicker than under the surrounding canopy due mainly to direct exposure to short wave solar radiation. Hence, the runoff hydrograph from a clearcut tends to peak higher than the under natural forest cover. In order to predict these impacts on a watershed basis one must consider the elevation of the harvesting. Snow accumulation increases and melt occurs later with increasing elevation. A low elevation clearcut within a watershed may have no affect on peak flow because the additional discharge is released prior to seasonal watershed peak flows, whereas a high elevation cut may have a considerable impact because the additional water is released when the hydrograph peak is occurring.

Another category of peak flow that may occur in the hybrid coast/interior and the interior is the rain-on-snow peak. Snowmelt rates may be increased by forest cover removal due to exposure to wind.

Although various hydrologic models are available, none are suitable for predicting the impacts of various spatial harvesting patterns on runoff.

3.2 Sediment - Pierre Beaudry, MoF

The impacts of forestry on watershed sediment yields is at the top of the list of forest management issues. Most of the concern regarding sediments, however, currently centres around impacts on fisheries or recreational water quality; relatively less attention has been paid to concerns about impacts on domestic water supplies, although the public has started to focus debate on those impacts in at least some areas of the province.

There are programs to study watershed sediment budgets in a number of regional offices of the Ministry of Forests. Sediment budgets document the sources, sinks, and pathways of sediment production, transport and deposition over both time and space. A review paper on sediment budget studies in the Prince Rupert Forest Region is provided in Appendix F.

It is important to look at the whole watershed when trying to understand sediment yields and the impacts of forestry activities on those yields. For example, clear-cutting does not itself generate a lot of additional sediment in a watershed; roads are much more important sources of additional sediment in most watersheds. In addition, we need to understand the importance of sediment generated by roads relative to sediment inputs from natural sources. Both the sources and quantity of natural sediment yields vary from watershed to watershed. There cannot, therefore, be an absolute standard for turbidity. There is also temporal variability in sediment yields, both in terms of when sediment is generated and its actual impacts. For example, sediment is of most concern to fisheries in the spring.

Monitoring is now trying to look at both natural and human-caused sources of sediment in watersheds in order to assess the relative importance of each to the total sediment budget, and how their importance changes over time (e.g., within and among years). An important question in most monitoring programs is the appropriate frequency of sampling (e.g., discrete vs. continuous measurements). What is the most appropriate sampling design to answer the desired questions given the natural dynamics of the system and financial constraints? Tools and methodologies are needed to answer user group questions. Some important questions scientists and managers need to answer before developing such tools are:

- How many sediment budget studies do we need? Is each watershed unique or can we make generalizations across a group of watersheds? What is the appropriate stratification of watersheds for producing such generalizations?
- How much and what type of information do we really need?
- What are our objectives? a risk assessment? a predictive model?
- Is a model really realistic?
- What is the relative importance of natural vs. human-caused sources of sediment?
- What are our priorities regarding research, management and the development of analytical tools?

3.3 Chemistry - Rick Nordin, MELP

Much less is known about the effects of logging on water chemistry than on suspended sediments. Many of the impacts of logging on water chemistry, however, tend to be linked with suspended sediments. The most important water quality concern after suspended sediments is elevated nutrient inputs, particularly nitrogen and phosphorus. In general, removal of the forest cover tends to increase nutrient output due to increased decomposition and mineralization and reduced uptake. Changes in forest hydrology also play an important role in this process.

Increases in nutrient concentrations are generally not a direct concern with respect to human health since they rarely exceed drinking water quality guidelines in surface waters. Of much greater concern are their effects on algal growth. The most obvious impact of algal blooms are aesthetic (taste and odour). In some cases, a bloom (e.g., blue-green algae), can render a water body toxic to livestock. In addition, the efficiency of chlorination is reduced by the presence of algae, and the formation of disinfection by-products (DBPs) such as trihalomethanes (THMs), a human health concern, is increased.

Nitrogen outputs tend to increase the most following clear-cutting - up to 10 to 20 times more in terms of weight/unit area. Other nutrients are not an immediate concern, although they may prove useful as indicators of an impact. What is most needed is an evaluation of the increase in nutrient output relative to natural background levels which naturally vary from watershed to watershed, as well as over time (analogous to the situation with sediments).

Toxic contaminants (e.g., herbicides) are often identified as a concern surrounding forestry activities in community watersheds. Toxicants, however, are not considered a large problem from a human health perspective. Of greater concern is their potential effects on watershed ecosystems. The introduction of toxic chemicals, however, is considered an important risk by the general public.

There are numerous questions regarding the design of an appropriate monitoring program to diagnose the effects of forestry on drinking water quality. Impacts are quite complex. When, how and what should we monitor? The parameters in the Canadian Drinking Water Quality Guidelines have little relevance. We need to monitor characteristics more directly related to ecosystem stability. Monitoring frequency is also an important issue with respect to water chemistry. Weekly measurements are probably not that relevant given the high amount of natural variability in many parameters. Biological indicators may prove useful but few have been developed.

3.4 Health - Barry Willoughby, MoH

About 86% of British Columbia's population on community water systems, rely on surface waters for drinking water. Only simple disinfection is provided for most water systems. Surface waters also carry a lot of microbiological contaminants. Some people are now trying to make a link between logging activities in community watersheds and water-borne disease outbreaks. The risks, however, may be overstated. There are multiple agencies involved in the management of water and drinking water quality. The Ministry of Health is responsible for surveillance and routine monitoring drinking water quality at the tap; but it does not have a

similar responsibility for private supplies.

The first known outbreak of Giardia in the province occurred in 1981 at 100 Mile House. Additional outbreaks occurred in 1986/87 in Penticton, Kelowna and Creston. Since 1980 there have been 16 known outbreaks of waterborne disease throughout the province, with sixty percent of these caused by *Giardia*; most of the other outbreaks were caused by *Campylobacter* and *Salmonella*. It is often difficult, however, to trace the cause of an outbreak to a particular organism. There have been no known outbreaks of *Cryptosporidium* caused by drinking water in the province (there was one outbreak traced to a swimming pool). B.C. has the highest incidence of enteric infections of any province in Canada; the incidence of enteric infections is also rising. While this may be partly due to increased reporting, data may underestimate the problem since many people do not go to the doctor, and those that do may not be correctly diagnosed. Boil-water advisories in B.C. have also risen in recent years.

There are about 1200 community water systems being monitored in B.C. About 600 of those are from surface supplies, many of which are very small. Ministry of Health staff had little authority until a regulation was recently passed which requires water purveyors to provide safe drinking water. Some of those purveyors have subsequently directed their attention to wanting reduced activities in watersheds, given the costs of treatment and limited resources of smaller purveyors.

Research from the United States suggests that disease outbreaks are most common in areas where drinking water has been directly contaminated by sewage and there is inadequate treatment. Pathogens are not normally tested for in drinking waters but some *Giardia* monitoring has been done which indicates this organism is a relatively common contaminant of surface water. We do not know at what level it will actually cause an outbreak. Many fundamental questions remain. Is there a dose threshold? Are there genetic differences among individuals which impart resistance and are there significant differences among *Giardia* species? There has never been an outbreak on a lake in B.C., only on creeks or rivers. Could that be related to animal habitat? The outbreak at Creston has been attributed to a beaver living at the intake. Wild animals are therefore believed to be an important source of pathogens.

There does not appear to be a seasonality in outbreaks. There also does not seem to be a relationship between the presence of bacterial indicators such as fecal coliforms and *Giardia* cysts. Research into indicators of the presence of this and similar pathogens is a high priority. An additional priority is how to manage the large number of small watersheds (i.e., less than 100 people) which often have minimal resources for monitoring and treatment.

3.5 Limnology and Remedial Measures for Taste and Odour Problems in Capilano and Seymour Reservoirs - Chris Perrin, Limnotech Research and Development Inc.

Chris Perrin presented a summary of Limnotech's research for the GVRD into the causes of seasonal changes in iron and ammonia concentrations which contribute to taste and odour problems in water from Capilano and Seymour Lakes. A major conclusion of this research is that reservoir manipulations may modify upstream processes. His presentation is not summarized here. The research report is currently in draft form. The GVRD will be releasing a final report some time this spring.

3.6 Models - Tim Webb, ESSA Ltd.

Models are simply tools that can assist scientists and decision makers in understanding the implications of their assumptions on how the world works. At this workshop two main types of tools are relevant:

1) Conceptual models; and

2) Computer simulation models.

There are a number of advantages in constructing both of these types of models, including:

1) synthesis of current understanding,

2) determination of key gaps in information and understanding, and

3) helping to structure research and monitoring programs and priorities.

In addition, simulation models can be used to project potential futures and examine quantitatively the implications of certain assumptions and management options.

3.6.1 Conceptual Models

Conceptual models are commonly described using box and arrow diagrams to show the key components of the system being described and the linkages between these. Once a box an arrow diagram has been constructed it can be used as a focus for determining what is known and not known about the boxes (system components) and arrows (processes).

One form of conceptual model that has been found to be useful in environmental impact analysis has been the **Impact Hypothesis.** This is simply a box and arrow diagram that represents the key system components and linkages that are hypothesized to cause a particular management action to result in impacts on a particular environmental component.

An impact hypothesis is an expression of the linked set of hypotheses on how a particular impact might occur. Once constructed, impact hypotheses can be used in a number of different ways including:

1) *To examine the likelihood of particular impacts by examining the probability that each of the necessary links can occur.* This can be useful both in projecting potential future impacts and in attempting to diagnose the likelihood that a particular mechanism was the cause of past problems.

2) *To provide structure to the development of monitoring programs.* By helping to determine which are the most likely and important impacts, impact hypotheses can help to focus on which system components should be monitored.

3) *To provide structure to the development of research programs.* By focusing on the critical pieces of the puzzle that are not well understood, impact hypotheses can help to prioritize research projects.

4) *An impact hypothesis is a good starting point for the development of a computer simulation model.* Since the important components and linkages are already defined all that is required is to determine how to represent the system components and what form the functional relationships (linkages) between them should take.

3.6.2 Simulation Models

Simulation models are largely bookkeeping tools that show the results of a particular set of numerical assumptions about how the world works. Simulation models are only as good as these assumptions and the data and parameters that are used with them. Because simulation models are generally based on the best current understanding of the system they can represent a mechanism for translating this understanding into a format that can be used in a decision making context. Simulation models also provide a means of testing assumptions about the behaviour of complex systems. A basic understanding of system processes does not necessarily produce an understanding of overall system behaviour. Unanticipated dynamics can emerge from the interaction of numerous system processes.

In the context of examining forestry impacts on drinking water quality in watersheds with relatively poor data, one of the key things a simulation model can do is show the range of different potential outcomes that are possible given uncertainty in model relationships and data for particular watersheds.

Personal computer technology has reached the point where it is possible to put a sophisticated modelling tool on the desk of every decision maker. These tools can be highly user friendly and can allow users to rapidly examine the potential for effects of a range of different management scenarios.

4.0 Needs/Users Discussion

4.1 Context

There are about 12,000 watersheds in the province which provide domestic water of some form (Allan Chapman, Ministry of Forests, personal communication). About 600-625 of those serve municipal waterworks systems. An additional 150 serve other organized users and an additional 125 provide domestic water to a large number of users each with their own intakes. The remaining 11,000 watersheds provide water for less than six users per watershed.

The median area of these watersheds is 8.6 km^2. About 60% of the watersheds are less than 8-9 km^2. Less than 10% are larger than 100 km^2. About a third of these watersheds are located in the Kootenays. Twenty percent are located in the Okanagan and another 20% are located in the Lower Mainland. The remaining 15% are on Vancouver Island. Digital maps of all community watersheds (except for Greater Vancouver and Greater Victoria Water Districts) are being developed by the Integrated Resources Branch of the Ministry of Forests. The maps only contain information on the areas of the watersheds; they will be used to determine the proportion of Timber Supply Areas (TSAs) in community watersheds in order to determine the implications of any withdrawals on the Annual Allowable Cut. They will also provide a map base to B.C. Lands to use for referrals.

4.2 Needs/Priorities

Four priorities emerged during the first plenary discussion on needs and priorities: 1) data and tools for **risk assessment**; 2) data and/or tools to **remove subjectivity** (or in some cases the appearance of subjectivity) in watershed management; 3) the need to develop **monitoring standards**; and 4) the need to facilitate the **exchange of knowledge and information** among agencies and regions on this topic.

Risk Assessment

Given the high degree of uncertainty surrounding the impacts of management on drinking water quality, many participants felt that the development of integrated risk assessment tools was a high priority. This also makes sense given the relative importance of stochastic episodic events in linking forestry activities to water quality impacts. Risk assessment tools might be used to develop rules for management under conditions of uncertainty.

Fundamental questions, however, were raised concerning the feasibility of developing such tools. Many participants, for example, pointed out the lack of representative data sets for many important processes. A strategic approach was advocated for developing new data sets. For example, scientists need to identify and rank the range of processes that should be quantified to perform a satisfactory risk assessment. It might then be possible to develop risk rules based on these major processes and basic data. Interestingly, impact hypotheses represent one tool for identifying and ranking processes for a risk assessment.

An important challenge is to make the risk assessment credible to the public. Many participants noted the need to include socioeconomic data. Cost/benefit considerations should be made explicit in future analyses (e.g, the financial trade-offs between preventing degradation of raw water quality vs. treatment to meet standards for drinking water). Many of the socioeconomic implications of management have not yet been quantified. The possibilities for reducing identified risks should also be identified and assessed. For example, there may be differences in the risks posed by a particular management activity depending on the types of guidelines used to guide that activity.

Additional questions were raised concerning the appropriate temporal scale over which to assess risks (i.e., short- vs. long-term impacts), and the manner in which those risks should be weighed.

Increased Objectivity in Watershed Management

Many participants expressed a desire to remove the apparent subjectivity and high degree of uncertainty in community watershed management. Risk assessments are one tool for accomplishing this objective. Monitoring of baseline water quality, however, is also required, partly to provide quantitative information on the relationship between watershed activities and impacts on water quality, but also to reduce unreasonable expectations among the public concerning "natural" drinking water quality from a given watershed. Public education was identified as a high priority. The public needs to understand that water quality is naturally variable over both time and space.

Some workshop participants also expressed the need for tools to more objectively manage community watersheds for multiple uses, if that is indeed a management objective. The risk analyses proposed above focus mostly on the trade-offs between timber extraction and drinking water quality (both raw and treated). The credibility of risk assessments with the public may be increased if additional values are also included such as biodiversity, other old-growth values, recreation and minor products (e.g., mushrooms and berries). Water quality, however, will likely still receive the greatest weight.

Interestingly, more rigorous assessment of the trade-offs among multiple values may serve to educate the public about other trade-offs. For example, if logging activities are subjected to a rigorous risk assessment, recreational activities in those watersheds might be subjected to the same analysis. The effects of forest age on water quality might also be addressed by these analyses. Some public groups argue that old-growth, for example, produces the highest water quality. The effects of logging on water quality should be assessed relative to the effects of fire or insect damage.

Monitoring

There are currently multiple and sometimes competing objectives behind monitoring programs in most community watersheds (see Appendix E for a review of MoELP monitoring programs). Monitoring guidelines in community watersheds were identified as a high priority. Impact hypotheses provide one tool for developing guidelines. Those guidelines, however, should be tied into clear objectives or questions. Different types of monitoring will address different

types of questions. Some management needs require more data than others. Some participants argued that many monitoring programs currently have too many monitoring objectives. We need to prioritize objectives and develop minimum standards.

Baseline monitoring was seen as a high priority. We need to information about the intrinsic variability of relevant indicators, both over space and across time. Such information would be useful for determining the appropriate sampling frequency and extent, both in time and space. Many monitoring programs may actually provide incorrect information about impacts or risks, especially those associated with episodic events. Intensive studies may say little about processes in other watersheds if "representative" areas are not chosen. Few data are available for most watersheds and more emphasis on gathering baseline data in representative watersheds is required. Ideally, baseline information would be gathered before management activities are undertaken.

Baseline monitoring provides a useful foundation for subsequent trend monitoring. Without such information we cannot determine whether water quality has really changed. Some participants argued that public perception is an unreliable indicator of changes in water quality. Changes in perception may be the result of an increase in public standards, rather than a real change in quality. We are ultimately interested in reducing false expectations and increasing public understanding of water quality issues.

Baseline and trend monitoring also provide data for exploring correlations between water quality parameters and management activities - e.g., the relationship between forestry activities and downstream water quality. The most useful monitoring programs, however, are those designed to assess how water quality changes as it moves through the watershed, rather than simply at the water intake. Simple monitoring will not produce statistically defensible evidence of cause-effect relationships; only a replicated experiment can do that. These data, however, will increase our understanding of watershed processes, and provide useful input into risk assessments for management purposes.

Workshop participants also pointed out the need for "goal posts" for water quality at the intake and in the watershed. Such goal posts would be useful for regional comparisons. There are no "standards" for raw water quality but MOELP does have "criteria" to protect ambient water quality which are approved and working. By policy, the Ministry of Health still uses the raw water quality standards published in the 1982 B.C. Water Quality Standard. The Canadian Drinking Water Quality Guidelines only address water quality at the tap. Raw water quality also varies both spatially and temporally. Should there be an "action level" for raw drinking water quality? Do we want the best quality water at the intake or the tap? The answer to these questions may ultimately rest on the type and cost of available treatment relative to options for controlling water quality at the intake. Once again, a cost/benefit assessment, explicitly incorporating uncertainty, is needed.

Knowledge/Information Exchange

Many workshop participants expressed the need for more access to information, perhaps in the form of a central data base or a clearing house for research results. There is a need to catalogue what types of research or management are being attempted, and to share results of these activities, across both agencies and regions.

A central database or catalogue of research/management activities and results would also provide a more synoptic view of water quality in community watersheds. Many participants identified the need for a more regional understanding of patterns in natural sediment yield, water chemistry and microbiology, as well as regional differences in the effects of management activities on those endpoints. This information would not only increase understanding but also facilitate education to reduce unreasonable public expectations about water quality. In order to facilitate information exchange and increase understanding (i.e., generalizations of research or monitoring results), however, we need a better stratification of watersheds - i.e., according to area, location, condition, types of use, etc.

Emerging Issues

Many participants identified a need to take a more proactive approach to identifying and confronting emerging issues in community watershed management. For example, global climate change has implications for water yield and quality (chemical and microbiological). Continued decreases in snowpack accumulation and runoff in southern portions of the province might create support for more proactive management of water yield through forestry operations. Participants, however, recognized the tremendous uncertainties currently surrounding global climate change. More immediate concerns might include effects of acid rain or other air pollutants on water quality in certain areas of the province.

5.0 Subgroup Summaries

There were three subgroups at the workshop, each concerned with a different set of impact endpoints: sediment, chemistry and health. The charges to the subgroups were:

- What are the hypotheses that link activities to endpoints (indicators)?
- How good is our understanding of these hypotheses?
- What existing data sets and/or research activities could contribute to understanding/model?
- What analytical tools/models are already available to support watershed management?
- What information would we require to apply those tools/models?
- What are the key data gaps?
- What are the research/monitoring/modelling priorities?

The results of subgroup discussions are summarized in the following sections.

5.1 Sediment Subgroup - Facilitator: Tim Webb, ESSA Ltd.

The members of the sediment subgroup felt that a significant amount of work had already been carried out describing the various types of water quality impact from forest activities and that it would not be useful to repeat this synthesis at this meeting. One of the main activities that has been responsible for this existing synthesis is the work being done by the **Community Watershed Committees**. These committees have been developing guidelines and were referred to extensively at the meeting as being an important source of information.

Because of these existing synthesis activities the group spent only a short amount of time discussing impact hypotheses. Following this the majority of the discussion focused on the types of tools that would be useful in the current decision making context, the types of monitoring required, and changes that could be made to include the concerns for drinking water quality in existing activities.

5.1.1 Impact Hypotheses

Six main categories of impact were proposed. Each of these could be developed into an impact hypothesis if appropriate:

1) Road construction and maintenance including all types of roads and fire guards;

2) Direct impacts associated with forest harvesting activities, with the level of impact being influenced by the method of harvesting;

3) Effects of erosion control including stream bank and slope stabilization;

4) Silvicultural activities, in particular site preparation;

5) Range management activities and the effects of cattle; and

6) Long term forest cover management including harvesting and fire suppression specifically designed to improve or maintain the quality of water.

The last of these impact categories is particularly interesting and should be further investigated. The use of forest cover management to improve water quality is a strategy being employed by the Greater Vancouver Water District.

Two basic mechanisms of sediment impact on water quality were noted:

1) side slope failures at a particular point; and

2) chronic fines production.

The level of concern and potential for impact associated with the six categories of impact identified above will depend on the characteristics of the activity, the watershed, and the relationship between the two. Taking roads as an example, some of these characteristics include:

1) the slope stability category,

2) the timing and method of road construction, and

3) amount of drainage interference caused by the road.

For all activities it is important to consider the whole life cycle of construction, operation, maintenance, and decommissioning. The subgroup noted that the quality of work carried out by different crews can vary radically even with the same construction methods and guidelines. This underlines the need for training at the operational level. Training and education is discussed further below.

5.1.2 Synthesizing Current Experience and Understanding

The sediment subgroup recognized that a lot of data collection and synthesis activities are currently being carried out in this area. These activities represent attempts to codify our current experience and understanding of the relationship between forest management activities and sediment effects on water quality. The important related activities identified at the workshop were:

- The development of the regional **Community Watershed Workbooks**. As noted above, this activity is an important component of synthesizing current understanding. The second edition of the coastal workbook is currently being developed and will be

a substantial improvement on the first edition. It should be noted that these workbooks are still just screening tools designed to assess the relative levels of risk.

- The **Coastal and Interior Fisheries/Forestry Guidelines**. While these are focused on fisheries they address many of the same issues related to the impacts of forestry impacts on sediment input to surface waters.

- The **Ministry of Forests Erosion Control Committee** maintains reports of episodic events that could provide useful information on the risks of particular types of activities (Peter Jordan in Nelson, and Jim Schwabe in Prince Rupert).

- **Hydroclimatic regionalization** - In order to make general assessments of risk for particular watersheds and to be able to transfer understanding gained from case studies between watersheds it is important to be able group watersheds based on their hydroclimatic similarity. These approaches are based on various criteria such as peak flow and mean flow. Studies are currently being carried out in this area by both the Ministry of Forests and the Ministry of Environment, Lands, and Parks; however, these are not currently coordinated.

- Methods for **objective terrain comparison** are also required in order to be able to extrapolate experience in particular watersheds. Methods are currently being developed at UBC and may be very useful in the future.

- **Specific guideline activities** such as the regionalization of the culvert guidelines can provide useful operational information.

- The **Federal Model Forest** initiative may be a source of useful information in the future.

- Various intensive **experimental watersheds** can provide useful data and are an important method of improving our scientific understanding of the problem. These include Carnation Creek, and the Tsitika study.

- The **major water districts** (especially Vancouver and Victoria) have a range of specific initiatives in the watersheds they manage that are relevant to sediment impacts.

In addition to these existing activities the subgroup recognized the need for a more structured process to systematically bring together case studies and experience and make this more available to assist decision makers.

5.1.3 Types of Models and their Application

The sediment subgroup used the term "model" in a broad context to include both computer simulation models and models or structures used for decision making.

It is important to understand that even the best simulation models have very definite limits to their power to predict. Sediment impacts on water quality are closely tied to episodic events, in particular the interaction of extreme weather events with the stability of various parts of the watershed. These episodic events may dominate the sediment levels in water. A simulation model can predict the increased risk of these episodic events, and it may be able to provide realistic patterns of how these might occur. A model cannot, however, predict exactly when, or even if they will occur. This means that in a management context even the best decision support tools (including models) will only be able to provide an assessment of the relative risks of different activities.

The sediment subgroup discussed two very different types of models:

1) **Scientific Models** - designed to be used largely in a research context to synthesize current scientific understanding, provide research direction, and provide insight that could be applied at a management level.

2) **Operational decision making models** - designed to provide useful information for making decisions with the relatively limited and 'fuzzy' data that is commonly available and with the current understanding of biophysical processes. These models would focus largely on the risks associated with particular activities rather than on detailed predictions. They would show how drainage basins of a particular type might typically behave in terms of the general levels and extreme values of particular indicators such as sediment levels at the water intake.

These two types of modelling must go on in parallel. On the one hand, it is necessary to put together the best tools and approaches to assist in day to day decision making. On the other hand, it is also necessary to use detailed scientific models to improve our understanding of how systems work. As the scientific understanding improves this can be passed on to improve the decision making models.

To assist the decision making process for community watersheds two key questions need to be addressed:

1) What kind of decision making models can be provided to the large number of community watersheds that have a minimal level of data?

2) What needs to be done in order to develop these models?

The most likely tools that can be provided to assist community watersheds with sparse data are those based largely on risk assessment. These could be either simple simulation models that focus to a large degree on the effect of uncertainties, or sets of rules such as those described in the community watershed workbooks. The types of information that would commonly be available to apply to a particular watershed might include:

- topography;
- a general description of the distribution of materials;
- information on forest cover;

- details of the proposed activities; and
- the proportion of the watershed that will be affected.

For extreme cases we can already use this information to generate an assessment of risk. For instance, logging road construction in a watershed with mostly 50^0-60^0 slopes and lacustrine soils is certainly high risk. What we need to be able to do is a better job of risk assessment in less extreme cases.

There are two ways of gathering the information to develop these tools:

1) compilation of empirical experience; and

2) further development of scientific modelling approaches that can provide generally applicable rules and relationships that are not data intensive.

Compiling experience in various watersheds is a powerful way of learning about the implications of particular forest management activities. Historical data can be useful for looking at the past patterns of events, but must be used cautiously where forestry practices have changed. Future monitoring is an essential part of increasing our database of past experience and this in turn is crucial for providing better risk data to watershed managers.

In addition to gathering empirical data on particular risks, it will be necessary to emphasize the development of methods of regionalization so that these experiences can be realistically generalized to different watersheds, and the collection of the data necessary to apply these regionalization approaches to the community watersheds.

5.1.4 Monitoring

The subgroup identified three main questions that should be used to drive sediment-related research and monitoring in order to be able to better manage forested watersheds for drinking water quality:

1) Documentation and better scientific understanding of the impacts of erosion on water quality.

2) How effective are the various activities that can be used for mitigating the effects of erosion on drinking water quality?

3) How effective are the guidelines in preventing erosion and sediment impacts on drinking water quality?

The subgroup discussed three different levels of monitoring (high, medium, and low intensity) with very different objectives. In addition to these, some of the other existing monitoring programs such as the Ministry of Forests Erosion Control Committee's landslide reporting system should be enhanced to better address drinking water quality concerns.

High Intensity

This level of activity would occur at 2 to 4 watersheds across the province and would be the focus of scientific activity. The group felt that this was probably the highest priority monitoring activity and the most likely to provide useful information. Costs could be as high as $200,000 per year or more depending on the details of the design.

Some key points that were made about these high intensity sites were:

- These types of studies are expensive and there is a strong need to coordinate among the different disciplines in order to get the most information from each study. This should include hydrologists, earth scientists, biologists, and water resource people.

- It is critical that there be some method of ensuring a base level of funding. These types of studies need to be carried out over a relatively long period of time and a consistent funding level is necessary to ensure that useful information is collected. At present these studies tend to be opportunistic and this is not the best way to improve our scientific understanding.

Some of the key research needs that could be addressed include:

- Understanding the natural patterns of erosion and slope failure. This is an important backdrop against which to examine and evaluate the effects of human activities.

- Sediment delivery, transfer, and storage.

Medium Intensity

This type of monitoring would have a more operational focus and could be carried out for perhaps $20,000 per year. The subgroup felt that these would be a lot less useful than the intensive watershed studies and would be most likely to happen as a result of particular concerns in specific community watersheds. The most useful types of activities that could be carried out at this funding level would be:

- preparation of a sediment production map,

- site specific sampling of certain water quality parameters,

- stage measurement at one location,

- one or two automated sediment monitoring stations (OBS - Optical Backscatter Sensor systems are relatively robust and could be appropriate),

- video flights over the watershed, ideally during or following particular storm events to see the overall pattern of sediment in the water courses, and

- measurements of bedload movement if these can be easily gathered from sediment traps associated with the water intake.

Low Intensity

Low intensity monitoring would again have an operational focus and would be triggered for specific watersheds. Costs would probably be on the order of $5,000. The two key components would be:

- one automated sediment (OBS) recording station at the water intake, and
- measurements of bedload movement if these can be easily gathered from sediment traps associated with the water intake.

It might be possible to place this type of low intensity monitoring system on quite a large number of watersheds throughout the province. This would provide a good picture of the patterns of suspended sediment at the water intakes of these watersheds. However, it would be hard to refer these back to particular activities and events in the watersheds unless there was a parallel monitoring study to keep track of these.

5.1.5 Additions to Guidelines and the Decision Making Process

The regional watershed workbooks are an important screening tool in the overall decision making process for community watersheds and the forestry/fisheries guidelines are also a useful information source. There are, however, some additional things that could be done to improve things:

1) The level of **slope stability** work needs to be kept to a very high level in community watersheds. The subgroup proposed that there should be relatively detailed mapping (1:5000) with additional focus on gullies, and 100% ground truthing in all operational areas.

2) For larger watersheds there is a strong need to develop procedures for assessing the potential for the **delivery of sediment** to the water intake. For smaller watersheds the worst case of 100% delivery can be assumed, but this may be too restrictive for large multi-use watersheds.

5.1.6 Education

The issue of education and training was raised a number of times during subgroup discussions. The need was seen to target two groups in particular:

1) The **general public** needs to be better educated on the overall issues of drinking water quality and the natural fluctuations that can be expected in a surface water supply system based on relatively natural watersheds. Some of the kind of points that need to be made are:

- Pristine, untouched watersheds do not have a zero risk of slope failures and negative effects on drinking water quality.

- Some of the coastal watersheds are in the Douglas Fir zone and are naturally fire dominated yet we have been suppressing fires for the last 43 years (Victoria). This will have an effect on the best way to manage these watersheds in the future.

If the public has a better understanding of these issues then their expectations may be more realistic.

2) **Forestry crews and operators** need to be better educated/trained in order to ensure that guidelines are followed and implemented in the best way possible and to reduce the current levels of operator variance. This is a particularly challenging task since functional illiteracy rates can be as high as 40-60% in some forest camps.

There are many opportunities for public education including programs for schools, university colleges, universities, and particular demonstrations such as the Seymour Demonstration Forest.

5.1.7 Recommendations

The main recommendations from the sediment subgroup were:

1) **Monitoring** - There needs to be better coordination of research and monitoring at the small number of intensive sites around the province to ensure that information necessary for improving assessment of the effects of management activities on drinking water quality is gathered. In addition, the episodic reporting system for landslides needs to be improved to ensure that appropriate information on water quality impacts is gathered.

2) **Regionalization/stratification** - Work on regionalization/stratification of watersheds needs to continue to ensure that it is possible to translate the results of case studies and one watershed to the implications for other similar watersheds.

3) **Synthesis of understanding/scientific modelling** - The development of detailed scientific models is a useful part of increasing our understanding of how human activities affect water quality.

4) **Decision model for watersheds with poor data** - The potential for the development of an operational model based on risk assessment should be further investigated. This should be strongly based on the express needs of decision makers.

5) **Amendments to guidelines** - Guidelines should be put in place to ensure that higher levels of assessment of slope stability and the potential for delivery of sediment are put in place for community watersheds.

6) **Education** - Education of both the public and operators within watersheds is a critical part of an overall water quality management strategy.

5.2 Chemistry Subgroup- Facilitator: Chris Perrin, Limnotech Research & Development Inc.

5.2.1 Introduction

The general focus of this subgroup was to apply conceptual modelling to examine relationships between chemical processes that link natural processes, management activities on forested land, and other manipulations with the quality of water that drains from community watersheds. To achieve this goal it was important to review purposes of the approach as they were examined in the plenary and concluding discussions of the workshop. The two main objectives of the workshop were:

1. To bring individuals together for discussion of relationships between forestry and water quality issues.

2. To explore analytical tools and develop impact hypotheses.

Certainly the first was achieved in the process of having the workshop. Many people with a variety of backgrounds from around the province were in attendance and there were enthusiastic contributions from most of the participants. In the chemistry subgroup, all participants actively contributed ideas and insight to make the process highly productive.

The second objective is somewhat more vague and thus, must be qualified with the question why there is interest in developing impact hypotheses in the first place. There was important discussion on this question both in the plenary and particularly at the beginning and end of the chemistry subgroup process. In summary, there were four key requirements for managing community watersheds that incorporate impact hypotheses or at least require an understanding of how components of community watershed systems are integrated.

1. Goals or Standards for Intake Water Quality.

Descriptive chemical data do not exist for many community watersheds, particularly the smaller ones. Managers are looking for comparisons with other drainages that may have similar biogeochemical processes and they are looking for bounds of variation that can be applied to measurements of descriptive variables in making inter-drainage comparisons. A range of processes and a short list of key measurements that can be used to quantify water quality conditions is required. This is a tall order as it requires relationships between watershed processes and water quality measurements both with and without manipulation from forest management activities. All of these requirements focus on the need to apply known relationships from one or more "index" drainages to determine the potential change in water quality that may result from a certain action in another drainage, not necessarily with high accuracy but at least "in the ball park." With this ability, reasonable goals can be assigned for intake water quality in the face of possible upstream manipulations when no data exist to describe functional relationships in the drainage of interest.

2. Monitoring Guidelines

There is a general lack of confidence in designing a monitoring program to track intake water quality. There may be too many expectations that monitoring will answer "process oriented" questions compared to its main function of providing a signal of temporal and spatial change. There is some suspicion that monitoring may not be detecting these changes. This uncertainty requires an improved understanding of system function that may be achieved using a conceptual modelling process. A model may form the basis of data collection, or at least point out where most uncertainty exists, and thus indicate what information is required to improve management confidence. With greater understanding of how a particular community watershed functions, managers will be better equipped to answer questions of what must be measured, what frequency is required, and where measurements must be taken to ensure that they have confidence in knowing the status of intake water quality and how it may change when various manipulations may be occurring upstream.

3. Future Water Quality from Watersheds

There is general uncertainty of the effects of long range trends caused by allochthonous processes on intake water quality. Processes include (but are not limited to):

- climate change and its influence on humidity, flows, and water yield;
- acidification and its influence on chemical speciation.

The development of impact hypotheses and a model may help to provide clues as to what to expect over the long term.

4. Ready Access to Information

This was regarded as the most important barrier facing managers having to make decisions on the use of water from community watersheds for which there is little descriptive or quantitative data. There was repeated comment on the need to have access to a system of data retrieval that may lend insight into changes in the quality of water that drains from both undisturbed watersheds and those in which one or more changes have occurred due to forest management activities.

To begin this process, a conceptual model is required to provide a framework into which known relationships can be inserted. Such a framework would also point out where additional data is required as part of ongoing study. This process requires that an easily usable database be available. Most important is the need to have current information accessible from a central facility that can be routinely used by people managing community watersheds.

There were other products that resulted from the process of developing hypotheses or qualitatively linking functional components of chemistry and activities on forested land. These were originally revealed during summary discussions in the subgroup but are useful to introduce

here. They provide a list of what is actually accomplished in the process of meeting the four water management requirements described above.

- Discussion of functional relationships is an educational tool that reveals important pathways that determine the magnitude of endpoint measurements (i.e., measurements of water quality at an intake).

- Linkages between important functional components are determined and can be used as a framework for decision making (e.g., when one or more components of the conceptual model may be manipulated, the model will show the path of potential impact that may include the water at the intake).

- In developing the conceptual model, awareness of functional processes is increased.

- "Stressors" or activities in a community watershed are identified and a relative ranking based on potential impact on water quality at the intake is proposed.

- In constructing the conceptual model, a rationale is also developed for the selection of endpoint measurements.

- A focus is provided for searching for information in the literature that describes the potential degree of change in endpoints associated with a particular stress or activity.

Each of these "products" was produced by the chemistry subgroup. Using a "box and arrow" conceptual model, stressors and watershed activities were identified, variables that control the influence of those activities were selected and short-listed and endpoint variables that affect aesthetics, ecosystem processes, and drinking water quality were determined.

5.2.2 Spatial Scope

In the chemistry subgroup there was repeated discussion regarding appropriate spatial boundaries: would the conceptual model include pipe ecology and reservoir management or was it to be limited to processes strictly related to forest management activities, not including other manipulations? Although the focus of the workshop was directed at forestry, it was also evident that the chemistry of water supplied via an intake can be altered by physical and chemical processes in reservoirs and thus modify direct effects of forestry activities.

The subgroup decided to include reservoirs and the management of water contained therein. Reservoir management was not considered water treatment, which is limited to chlorination, filtration, coagulation, etc. Those treatments may improve water quality but they have nothing to do with the source of potential water quality problems associated with forest management activities. The spatial scope, therefore, includes the highest watershed elevations down to and including reservoirs. The lowest elevation boundary is the intake, not including the water treatment systems.

5.2.3 Conceptual Model

A framework describing relationships between various forest management activities or stressors and water quality was developed as shown in Figure 1. The figure is hierarchical. Water quality is determined first by background processes, including the weathering of ambient bedrock as well as surficial geology, soils, precipitation chemistry, lotic and lentic chemical processes, and evaporation/crystallization processes. The integration of these processes is then influenced by each of the stressors, which were limited to:

- fire;
- use of petroleum products;
- herbicide and pesticide applications;
- fertilizer treatments;
- harvesting; and
- road building and use.

The potential effect of each of these stressors is determined by a group of variables common to all stressors and a group which is unique to each stressor. The resulting water quality can then be manipulated by the management of a reservoir, before the characteristics of water at the intake are determined through measurement of a group of endpoint variables. The endpoint data then provides information on the quality of water that can be stratified into aesthetic characteristics and health. Health is further stratified into ecosystem functions, and direct human health concerns.

Background Chemistry

Concentrations of chemical ions and other complexes provide a basis upon which the "natural condition" can be described. Typically these measurements would occur at an intake but it is likely they would also include sites at higher elevations in a watershed to provide information on natural spatial variation and temporal/spatial change due to the effects of stressors. For example, both surficial geology and soil chemistry may vary spatially; precipitation chemistry and aquatic processes may vary temporally, thereby altering the form and rate of transport of certain size fractions of chemical constituents. Measurements should be continued over a period of time sufficient to provide an estimate of natural variability.

The specific selection of variables describing background chemistry was not completed at the beginning of discussions. The list was expected to be closely related to endpoint variables, which were not evident until the details linking control variables to endpoints were outlined. The rationale was that the model in Figure 1 was designed to follow pathways leading to change in the "natural condition" which implies that endpoint variables must be similar to beginning variables to allow comparability. The only variables that were certain to be included were those which describe the chemical properties of water including, pH, conductivity, alkalinity, dissolved oxygen, and temperature, as well as those linked to biological processes which influence water quality, including organic matter (dissolved and particulate), suspended sediment, stream flow, and irradiance (photosynthetically active radiation (PAR)).

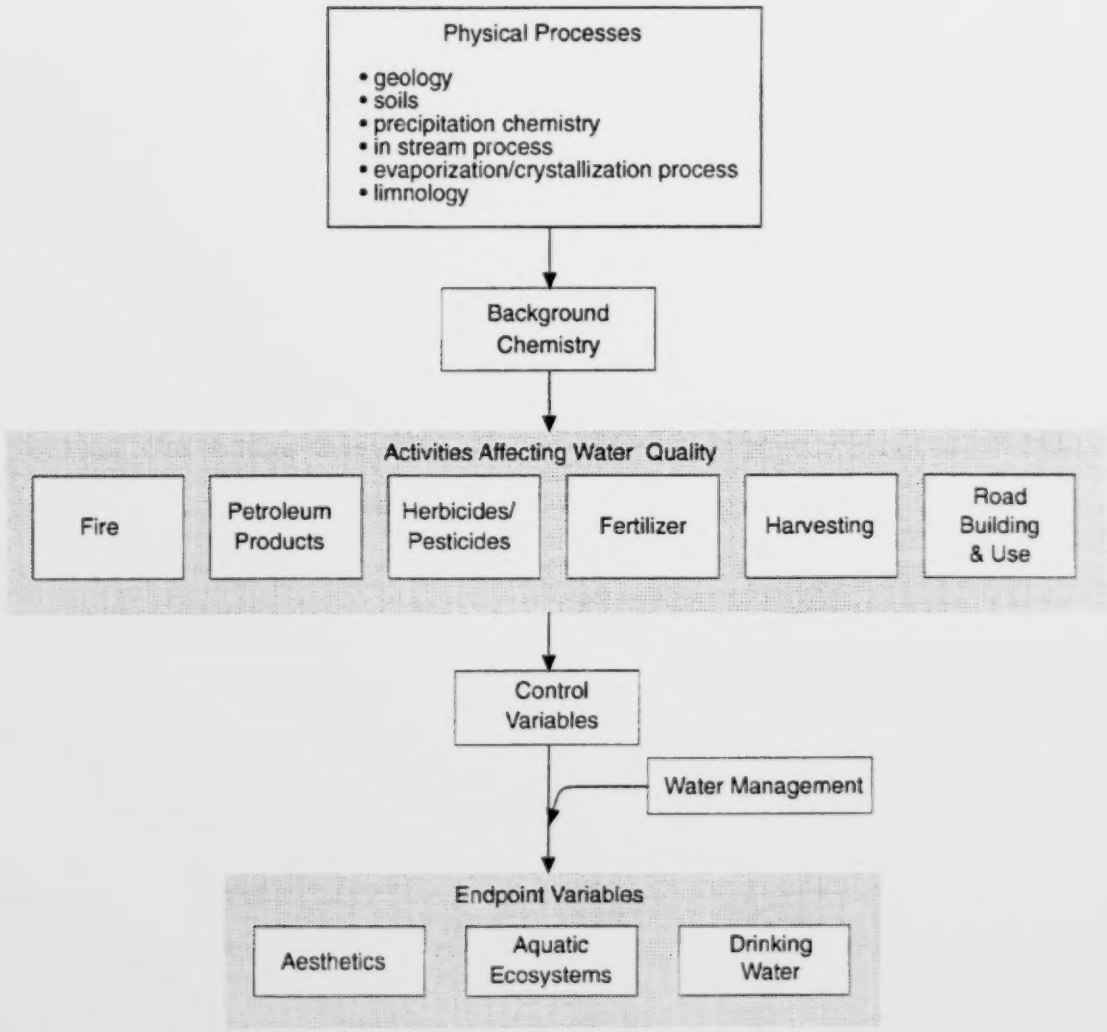

Figure 1 Framework used to describe the relationship between forest management activities or stressors and chemical water quality.

Forest Management Activities (Potential Stressors) and Control Variables

Although many potential stressors and activities were identified, all could be grouped into 6 main activities (Table 1) that may influence some aspect of water chemistry. These activities could be measured using a suite of descriptive variables that quantify the activity or stress. A list of "control variables" were also assembled which were thought to determine the degree of effect the watershed activity may have on water properties (Table 1). The control variables were viewed as being independent, acting directly on the descriptive variables that quantified the forest management action. In this sense, the control variables were crucial to the overall effect of the six main activities. It is important to note that the variable selections were based on the cumulative knowledge from all participants in the chemistry subgroup. Although technical rationale for the selections were briefly reviewed during subgroup discussions, the table is based on an *a priori* knowledge of relationships between a particular stressor and changes in water chemistry.

To avoid a long and unwieldy list of variables, the control variables were stratified to indicate if they were unique to the particular activity to which they were assigned or whether they were found to recur and thus be considered common variables (Table 1). From this exercise it was clear that within the group of more than 80 control variables originally listed in Table 1, there were 7 that were common for all watershed activities:

- area, area ratio (treated area/drainage area), or extent
- precipitation
- training, regulations, contingency plans
- suspended sediment concentrations
- time
- distance from water body or buffer width
- streamflow

A further 16 independent variables were found to be common in 2 or more groups (Table 2). Consequently, the selection of independent control variables may be visualized as fitting in three tiers in the box marked control variables in Figure 1; one tier represents the common variables that determine the effect of all potential stressors, the second represents variables that determine the effects of two or more stressors, and the third includes variable lists specific to each stressor. This stratification was necessary for eventually linking control variables with stressors, each link representing a specific impact hypothesis. These linkages would eventually be quantified beyond the conceptual modelling stage, a process that was beyond the scope of this workshop.

Table 1. Listing of watershed activities, variables with which the activity can be measured, and variables that potentially determine the degree of effect by the watershed activity on water chemistry.

Watershed Activity	Descriptive Variables to quantify the watershed activity	Control Variables	Common (C) or Unique (*)
Harvesting	• decision to harvest (yes or no) • change in soil solution parameters • change in concentrations of chemical parameters in streams • water temperature change • concentration of suspended sediment • stream flow • dissolved oxygen	• Buffer width influencing blowdown and riparian stability • area • method of harvesting • burn (yes/no) • post harvest treatment (presence/absence) • precipitation • slope • soil properties • slash loading into stream	* C * * * C C C *
Herbicides and Pesticides	• decision to use herbicides or pesticides (glyphosate; garlon; 2,4,D; 2,4,5,T; Picloram; Bt; other insecticides): yes or no.	• rate of application • method of application • wind velocity • precipitation • width buffer zone • temperature • type of chemical • type of carrier • spill frequency • training and contingency • regulations • UV radiation • pH • suspended sediment • streamflow • chemical transformations • degradation products	C C C C C C * * C C C C C C C C *
Road building and use	• change in stream flow • change in suspended sediment concentrations • change in NH_4^+ and NO_3^- transport • change in dissolved solids concentrations	• road grade • construction quality • number of bridges • water diversion (yes or no) • extent (length of road) • proximity to water body • precipitation • slope and stability • # vehicles • maintenance • timing of use	* * * * C C C C C * *

Watershed Activity	Descriptive Variables to quantify the watershed activity	Control Variables	Common (C) or Unique (*)
Fertilization	• decision to fertilize with urea, ammonium nitrate, ammonium phosphate, sulphur coated urea, sulphate, borate, TSP, hydroseed solution (NPK) • increase in concentration of the nutrient applied (spike followed by exponential decay)	• rate of application • precipitation • pH • depth of organic layer in forest soils • N:P is water bodies • method of application • presence of stream or lake • airborne drift (wind) • buffer width • loading and transportation methods • streamflow • soil type • temperature • ratio of treated area to drainage area (dilution factor) • type of chemical • suspended sediment concentration • colour • turbidity	C C C C C C C C C C C C C C * C C C
Petroleum Products	• presence/absence of hydraulic fluids diesel fuel, lubricants, gas	• number of vehicles • proximity to water body • contingency for clean-up • maintenance of equipment • disposal plan • vehicle access • fuel storage criteria • type of fuel • amount of spill • precipitation • stream flow • training • response time • time • degradation rate	C C C * C C * * C C C C C C C

Watershed Activity	Descriptive Variables to quantify the watershed activity	Control Variables	Common (C) or Unique (*)
Fire	• occurrence of fire (yes/no) • presence/absence of retardants (ammonium phosphate, iron oxides, iron cyanide) • presence/absence of foams (fatty acids)	• area • treatment methods • type of retardant • pH • precipitation • contingency plans • season (rate of growth) • severity of burn (fuel consumption) • nature of fuel • soil depth and type • proximity to water body • rate of regeneration after fire	C * * C C C C * * C C *

Table 2 Independent variables controlling effects of two or more potential stressors.

Common Independent Variable	Watershed activity affected by independent variables
slope	Roads, Harvesting, Fire
soil properties	Roads, Harvesting, Fire
application rate	Fire, Pesticides, Fertilizers
wind velocity	Fire, Pesticides, Fertilizers
temperature	Fire, Petroleum, Pesticides, Fertilizers
spill frequency	Fire, Petroleum, Pesticides, Fertilizers
irradiance	Fire, Pesticides, Fertilizers, Harvesting
pH	Fire, Pesticides, Fertilizers
chemical speciation and degradation products	Fire, Pesticides, Fertilizers
N:P in aquatic ecosystem	Fire, Fertilizers, Harvesting
method of application	Fire, Pesticides, Fertilizers
colour	Fire, Fertilizers, Harvesting
turbidity	Fire, Fertilizers, Harvesting
rate of growth	Fire, Pesticides, Fertilizers, Harvesting
# vehicles	Fire, Petroleum, Harvesting, Roads
spill magnitude	Fire, Petroleum, Pesticides, Fertilizers

Water Management

Water management is another group of independent control variables that act secondarily on output from action by the stressor control variables. Processes in water management are limited to the effects of reservoir manipulations. An example is the resuspension of particulates and associated changes in iron and ammonium concentrations as described in the Perrin talk during the plenary session. Water management may also include reservoir restoration activities such as hypolimnetic aeration, artificial circulation, and water diversions. Given these criteria, variables that describe water management include:

- change in reservoir level
- aerator output
- index of water transfer or diversion
- level of water withdrawal

Independent variables that exert control over water entering the reservoir (the end product of upstream stressors) include:

- water level
- dissolved oxygen profile (by depth)
- temperature profile (by depth)
- number of inflow and outflow tributaries
- bank slope
- sediment particle size distribution
- pH
- flow
- basin bathometry
- area
- retention time

Endpoints and Linkage to Background Chemistry

Endpoints are a list of dependent variables that are considered sensitive to each of the stressors and water manipulations that may be active within a community watershed. The endpoints are mostly measured at the intake but they may also be measured at other locations if information on time course changes are required for subdrainages where specific manipulations are expected or are active.

The list of endpoints was actually developed in the course of examining changes in background chemistry associated with each of the watershed activities (Table 1). Using expertise in the subgroup, specific processes associated with a particular stressor were followed sequentially and variables that were repeatedly identified as being sensitive to each manipulation fell out of the discussion (Table 3). Since the intent of the conceptual model was to examine pathways that alter background chemical conditions, the endpoints can be considered the same as variables that describe background chemical conditions.

An application of the endpoint (and background chemistry) list is that it includes measurements that are required from a community watershed for which there are no data. By collecting this information at strategic sites that are defined according to basin morphology and potential stressors (i.e., site specific criteria), a water manager will have assembled information to characterize the biogeochemistry of the drainage before any manipulation by forest management activity takes place. If one or more stressors is active, the data will be suitable for direct comparison to water quality standards or relevant literature.

Table 3. Endpoint variables stratified by aesthetics and health showing association with forest management activities.

ENDPOINT DESCRIPTION E: ecosystem indicator D: drinking water indicator A: aesthetics indicator	ENDPOINT VARIABLE	FOREST MANAGEMENT ACTIVITY ASSOCIATED WITH THE ENDPOINT
D,E	pH	all except petroleum products
D,E	nitrogen species	all except petroleum products
E	phosphorus species	all except petroleum products
A	colour	Fire, Harvesting, Roads
A,D,E	turbidity	Fire, Harvesting, Roads
A,D,E	Organic carbon fractions	Fire, Pesticides, Harvesting, Roads
A,D,E	dissolved oxygen	all except petroleum products
A,E	iron species	Fire, Harvesting, Roads
A,E	manganese species	Fire, Harvesting, Roads
D,E	HCN and products of retardants	Fire
E	sulphate	Fire, Fertilizers, Harvesting
A,E	temperature	Fire, Fertilizers, Harvesting
D,E	pesticide products and Bt	Pesticides
A,D,E	hydrocarbon products	Petroleum, Pesticides, Roads
A,D,E	H_2S	Harvesting, Roads
A,D,E	algal biomass and cell counts	all except petroleum products
A,E	invertebrate enumeration	all except petroleum products
A,D,E	bacteria counts	all except petroleum products

5.2.4 Data Sources and Gaps

The issue of what data were available or missing to eventually use in a more quantitative model was addressed too late in the subgroup session to address in any detail. However, the following generalizations were evident:

- There is an abundance of data describing the effects of a variety of harvesting methods on the chemical characteristics of water. This literature should be reviewed before any new study is considered.

- The effects of fire suppression and the use of foams on water quality needs study since relationships are poorly understood.

- The fate and effects of most fertilizer treatments are well-known. Relationships can be found in the literature.

- Although the breakdown products of pesticides are well-known, the fate and effects of these are not. This is particularly true for the various carriers in which the active ingredients are transported. More research is needed on this issue.

- The action of petroleum products in freshwater is not directly established from local studies but there must be data from work on the Great Lakes, the Alaska Pipeline Development, and a host of marine literature. A literature review is required before any field study is undertaken. There was no direct expertise in the subgroup to address specific sources of data.

- Although a great deal of data on the effects of roads on suspended solids exists, relationships between the use of explosives, rock weathering rates, flow alterations, and stabilization on water quality endpoints may not be as clear. A literature review is required, particularly of literature dealing specifically with mine developments.

Perhaps the greatest lack of information is that associated with the effects of these activities at the scale of an entire watershed. Studies at this spatial scale are relatively few and there may be a need to continue efforts to maintain long term studies of a variety of stressors.

It was interesting that so-called "training" became evident as an important control variable. The subgroup did not have the expertise to determine specific variables to quantify training although we thought there must be many available (e.g., through WCB or union data files). The relationship between training, contingency plans, or other organizational criteria and water quality endpoints is poorly understood. Considering their importance, these relationships should be studied prior to further model development.

5.3 Health - Facilitator: Trent Berry, ESSA Ltd.

There are two broad categories of health concerns related to forestry activities in community watersheds and their effects on drinking water quality: toxic contaminants and human pathogens. The health subgroup focused mostly on the latter, leaving many of the chemical issues to the chemistry subgroup. Toxic contaminants, however, were discussed in greater detail in the context of disinfection by-products (DBPs) such as trihalomethanes (THMs).

A variety of pathogenic bacteria (e.g., *Campylobacter*, *Shigella*, and *Salmonella*), viruses (e.g., *Norwalk* and *Hepatitis A*) and parasites (e.g., *Giardia* and *Cryptosporidium*) are potentially transmitted via surface waters. Sources of these pathogens include humans and wild or domestic animals, although the importance of wild animals as a source or carrier of human pathogens is still controversial. Parasites, particularly *Giardia*, are currently the greatest health concern, at least among the general public. In addition, many smaller communities do not yet disinfect their water, making the risk of bacteriological contamination an on-going concern in parts of the province.

Direct linkages between human activities in community watersheds and disease outbreaks have not been established in B.C. Subgroup participants argued that public perception, rather than science, is driving this issue. That does not mean that there is no reason for concern. Pathogen movement through watersheds is not yet well-understood. Furthermore, from the perspective of human health, public perception may be as important as any real risk. That perception represents an additional stress in people's lives. In addition, it has increased the use of bottled water and point-of-use filters. It also results in people turning to alternate "pristine" sources. Standards for bottled water are questionable, and point-of-use filters represent an important health risk if they are not properly maintained.

Interestingly, the equally pervasive perception that B.C.'s raw drinking water is pure and healthy is also dangerous. There is a lot of opposition in many areas to making improvements in treatment. There is a perception that "pristine" water exists in untouched watersheds. No-access, however, does not mean no human health risks. Unauthorized access and wildlife may both introduce pathogens to a community water supply. The Ministry of Health may require disinfection of community water supplies even when water is drawn from watersheds with "no access." Unfortunately, many smaller communities are still not disinfecting their water.

Obviously, perception can indirectly increase health risks. Subgroup participants, however, argued that it is still necessary to separate public perception from scientifically identified threats for the purposes of analysis and management. The former may require more education and dialogue, while the latter need to be addressed through research. The fundamental question to be addressed: Does logging *significantly increase* the risk of water-borne disease? Appropriate criteria for judging significance must be developed. Some participants advocated cost/benefit criteria.

The health subgroup necessarily focused on very fundamental research questions. Drinking water quality has typically been viewed from an "end-of-the-tap" perspective. Under the *Health Act*, the Ministry of Health has no mandate over land use in community watersheds. In addition, the *Water Act*, administered by the Ministry of Environment, Lands and Parks is primarily oriented towards the allocation of water, rather than protecting water quality from the perspective

of human health. An "ecosystem approach" to the management of drinking water does not exist. The "ecology" of human pathogens in community watersheds is only beginning to receive serious study in B.C. A systems approach to assessing the health risks and total costs/benefits associated with forestry activities in community watersheds is needed.

5.3.1 Impact Hypotheses

The health subgroup considered a series of rudimentary impact hypotheses. These hypotheses were grouped into two broad categories: the *direct* and *indirect* effects of logging on drinking water quality parameters which are most relevant to human health. A rudimentary conceptual diagram linking both direct and indirect effects to human health endpoints is presented in Figure 2.

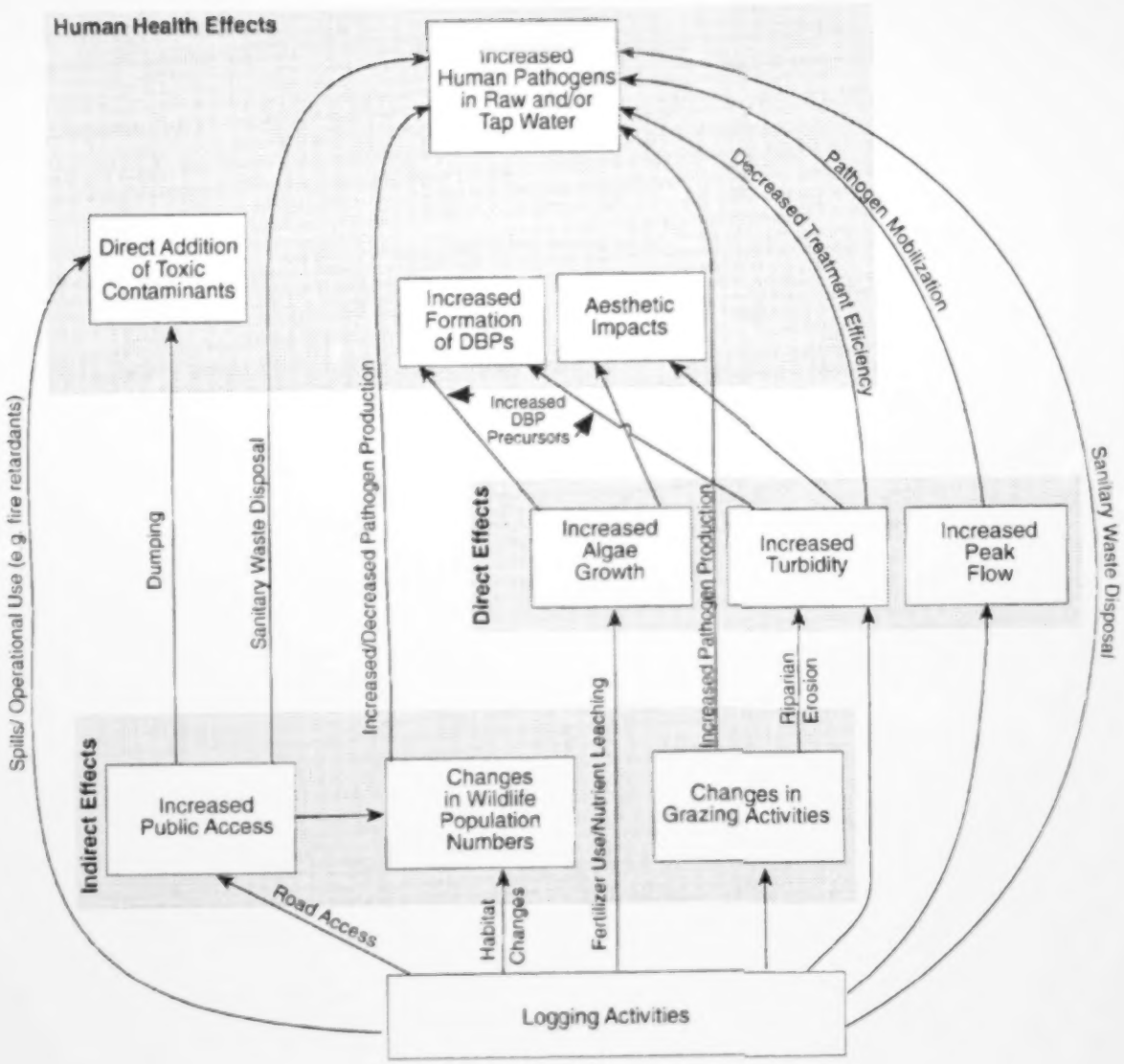

Figure 2 Summary of the direct and indirect effects of logging activities in community watersheds on drinking water quality and ultimately human health.

1) Direct Effects of Logging Activities

Changes in Sediment and Water Yields:

From a human health perspective, the most important direct effects of logging on drinking water quality are caused via increased turbidity and increased peak flows (the specific processes/activities responsible for these effects were not discussed in this subgroup) (Figure 3). The most obvious impact of increased turbidity is on drinking water aesthetics. Higher turbidity also reduces the efficiency of disinfection, thereby increasing the possibility of a disease outbreak. Suspended sediments and organic matter may also harbour adsorbed pathogens, increasing the number of pathogens per unit volume (although this processes was not believed to be very important). Increased peak flows, which are often associated with increased turbidity, also may mobilize additional pathogens in riparian areas, further increasing pathogen concentrations. Finally, high turbidity may increase the formation of various disinfection by-products (DBPs) such as trihalomethanes (THMs) which are believed to be a human health risk.

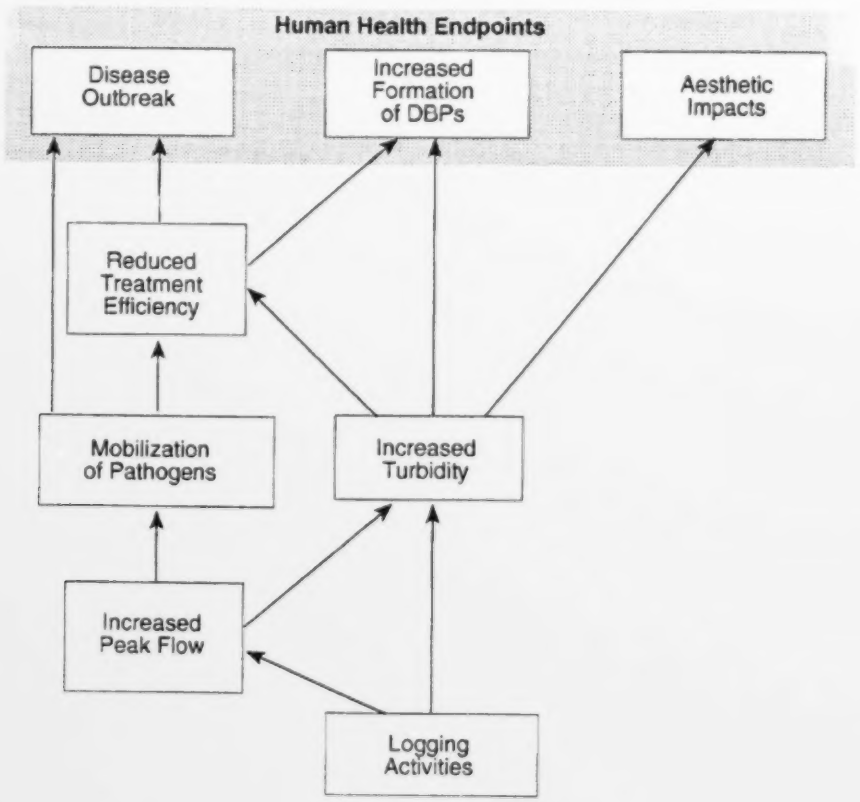

Figure 3 Selected direct effects of forestry activities on drinking water quality.

Interestingly, if communities respond to higher turbidity or increased fecal coliform counts by increasing chlorination, they may inadvertently increase the health risks posed by DBPs. The Ministry of Health is currently examining the level of THMs in different water supply systems; based on their findings, they may revise the standards for THMs. There are alternatives to chlorination but many are not feasible unless the water is filtered first (e.g., UV). Furthermore, in large systems chlorination is still necessary following treatment to prevent regrowth within the distribution system.

Studies in other jurisdictions show a correlation between increased turbidity and outbreaks. The actual causes of such outbreaks, however, is not known (e.g., the importance of pathogen mobilization vs. reduced treatment efficiency). The relative importance of various pathways identified in the impact hypothesis in Figure 3 are not well-understood. Workshop participants were not aware of any evidence linking increased turbidity or fecal coliform counts to *Giardia* outbreaks or other disease outbreaks in B.C.

Questions were also raised about who should pay for more elaborate treatment such as filtration. The majority of smaller systems do not have the financial resources to build such systems. If filtration is eventually deemed necessary to reduce the risks posed by logging, should the systems be installed by forestry companies as another cost of logging? Interestingly, this mechanism for "internalizing" any externalities which result from logging in community watersheds may result in cost-benefit analyses to determine whether the benefits of logging truly outweigh the costs (represented by the cost of filtration in response to the perceived risk of logging). There is still resistance among the public to filtration since it is seen as a "carte-blanche" to expand activities in community watersheds. Filtration also creates other problems such as disposal of filtered residues.

There are many other hypothesized direct impacts of logging activities. Many of these were seen as secondary from a human health perspective. Some of these are discussed briefly below.

Human Waste Disposal:

From the perspective of human health, disposal of human wastes during logging is perhaps the next most important concern following the effects of logging on turbidity and flow. Human wastes (both solid and liquid) are a potential source of pathogens, particularly when deposited directly in, or close to water (i.e., riparian zone). Feces deposited directly on soil surfaces near a stream or lake may be flushed into those waterbodies by rainfall or snowmelt.

Pit toilets reduce the risk of contamination (as long as they are actually used by workers). Pit toilets are increasingly being installed at work sites.

Use of Fertilizers:

Fertilizer use was not seen as a direct health concern, but rather an indirect concern through its effects on algae growth. Algae can reduce the efficiency of water treatment and increase the formation of DBPs. Algae, however, are mostly perceived as an aesthetic impact. Participants believed there was already good information on the impacts of fertilizer use (e.g., Chris Perrin's work).

Use of Herbicides:

The use of herbicides were not thought to pose a direct risk to human health, although public perception views their use as a health risk. More concern was expressed in the group about their direct effects on ecosystems. Some questions were also raised about the movement of herbicides adsorbed to sediments, but were not addressed any further.

Use of Road Salts:

The use of road salts was identified as a potential risk but was believed to be minimal on logging roads relative to highways.

Use of Fire Retardants:

Fire retardants contain nutrients and therefore pose many of the same risks as fertilizers. However, they also contain rust inhibitors, antibacterial agents and possibly cyanide which may pose as yet unexplored health risks.

Fuel Use/Storage:

Spills pose an important threat to drinking water quality (i.e., the introduction of toxic contaminants). Spills, however, are highly episodic and were not addressed any further by the subgroup.

Changes in Water/Soil Temperature:

Changes in soil or water temperature (and possibly chemistry) may increase coliform counts. However, the greatest impact is probably on algae growth, which directly affects aesthetics and indirectly affects health through the formation of DPBs and the reduced efficiency of treatment.

Increased Nutrients:

Logging can directly increase nutrient output to streams and reservoirs. Most increases, however, are not a direct health concern since they are well below guidelines. The most important impact is on algal growth which affects aesthetics, treatment efficiency, and the formation of DBPs.

2) Indirect Effects of Logging Activities

Increased Access

Logging roads increase access to previously closed watersheds. Greater access increases the risk of contamination with both toxic contaminants (e.g., dumping) and human pathogens (e.g., human waste) (Figure 4). If the watershed has good recreational features, roads are likely to increase recreational use of the watershed. Some IWMPs prescribe road deconstruction to address this problem, but the effects of barriers and deconstruction need to be assessed.

The actual risks posed by recreation depend on the type of recreational activity, the intensity of use, and the behaviour of recreationists. The greatest risks are posed by water-based recreational activities since users are more likely to defecate or urinate in or around water bodies. Watersheds which contain lakes will also likely experience the greatest increase in use. Terrestrial users (e.g., hikers) are believed to pose less risk of microbiological contamination than activities close to water, but still pose a risk nonetheless. Multi-day use (i.e., camping) is believed to increase the risk of contamination from any activity.

Increased recreational use may also indirectly increase fire hazard and sedimentation, but the relative effects of these on water quality was regarded as minimal. In addition, greater road access actually increases fire-fighting ability.

Range Use of Forest Lands

The greatest use of forest lands for grazing occurs in the Okanagan (where about 45% of grazing occurs in community watersheds), followed by the East Kootenays, the Cariboo, and in some lower elevation coastal areas. Cattle are known or suspected to carry *Campylobacter*, *Salmonella*, *Cryptosporidium*, and *Giardia* (in calves). Grazing is known to raise fecal coliforms in surrounding surface waters, but the effects of grazing on the presence and concentration of actual human pathogens (of which fecal coliforms is only a partial indicator) are not known.

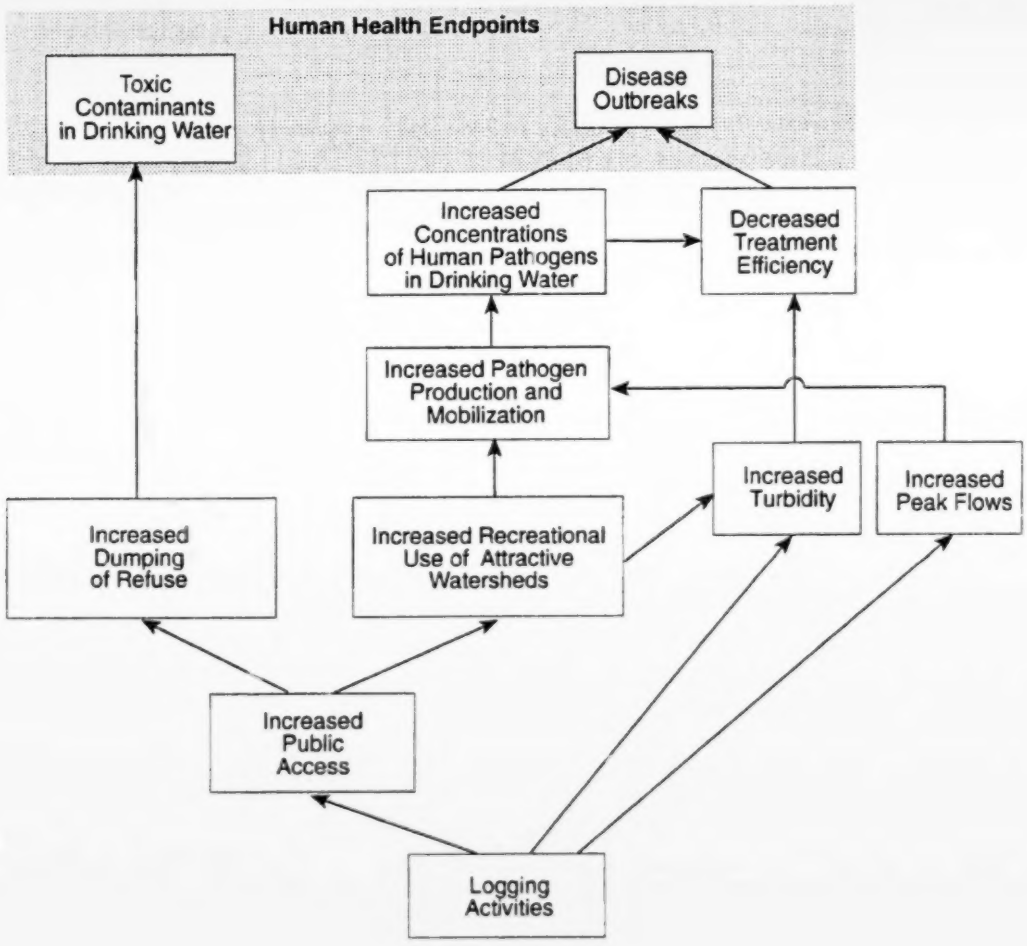

Figure 4 Indirect effects of logging on drinking water quality via effects on public access to community watersheds.

The effects of logging activities on human health via grazing activities are depicted in Figure 5. Logging activities often increase the access of cattle to riparian zones. Trampling of stream banks can cause erosion, thus increasing water turbidity. Increased turbidity, as outlined above, affects both the efficiency of treatment and the formation of disinfection by-products. Access to riparian zones also increases the risk of direct microbiological contamination of surface waters with any pathogens the cattle may be carrying. Riparian access is difficult to control

practically given the cost of constructing barriers. The timing of grazing may be important since green-up in the spring tends to occur first along streambanks thus attracting cattle even more to those areas.

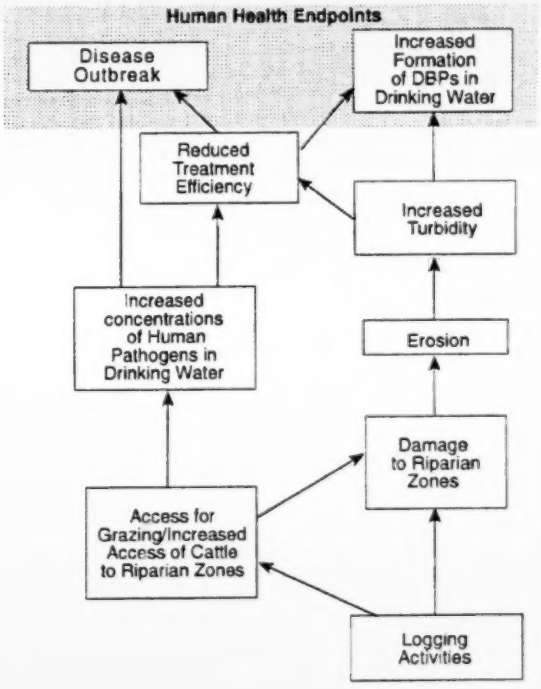
Human Health Endpoints
Disease Outbreak
Increased Formation of DBPs in Drinking Water
Reduced Treatment Efficiency
Increased Turbidity
Increased concentrations of Human Pathogens in Drinking Water
Erosion
Damage to Riparian Zones
Access for Grazing/Increased Access of Cattle to Riparian Zones
Logging Activities

Figure 5 Indirect effects of logging on drinking water quality via grazing activities in community watersheds.

Impacts on Wildlife Populations

The degree to which wildlife may harbour and transmit various human pathogens is still controversial. For example, beaver have been found to carry multiple species of *Giardia*, but the degree to which each can infect humans is not well-understood. The manner in which beavers actually become infected with the human forms of the pathogen is also not known. Beavers have been implicated in the *Giardia* outbreaks at Creston (1985, 1990), Penticton (1986), and Kimberly (1982); however, there have been outbreaks in other areas where no beavers were found in the watershed.

Both logging activities and the increased access to community watersheds provided by logging roads may influence both the levels of various wildlife populations and the presence of human pathogens in those populations (Figure 6). For example, logging can have positive effects

on beaver populations, the species currently of most concern from the perspective of human health. Road culverts provide additional sites for building dams and short-term changes to deciduous trees also favour beaver. Studies on the Queen Charlottes have demonstrated these effects of logging on Beaver populations.

Other species of wildlife may be positively affected (e.g., deer), but the risk those species pose to human health is not believed to be as important. Increased access (e.g., recreation and trapping) is believed to have a negative effect on most wildlife populations. Access may also be one source of the pathogens carried by various species of wildlife, although beaver are known to migrate large distances.

One question of great interest at the moment is the relative importance of wildlife and cattle in transmitting human pathogens. A common argument of advocates of grazing in community watersheds is that cattle do not pose any greater risk to human health than wild animals. One means of determining the importance of each may be to stratify watersheds according to whether they are grazed or not, and the intensity of grazing in each. Watersheds could then be monitored across a gradient of grazing use from none to high intensity to determine the effect of cattle on watershed microbiology (not just on fecal coliforms which are good indicators of bacterial contamination, but also parasites and viruses).

5.3.2 Research/monitoring/modelling priorities

Basic research remains the highest priority in addressing forestry-drinking water quality interactions from the perspective of human health. Changing or supplementing current or planned monitoring efforts would also provide valuable information for addressing suspected problems or public concerns. Public education is also a priority. Modelling opportunities are limited given our current understanding and minimal data sets. A systems approach to assessing human health considerations is required to support all of these efforts.

Specific recommendations include:

1) **Better screening of historical data** is required to look for correlations between land use (among other factors) and disease incidence/outbreaks, or other microbiological indicators. This will require a stratification of watersheds according to level and type of use. The Ministry of Forests can provide information regarding land use. The Ministry of Health has the data concerning disease outbreaks; however, most of these data are located in the local health units. As of 1992, information on the incidence of disease is now computerized, which should facilitate future compilation of a central data base.

There are questions as to whether the right kind of data is currently being gathered. Some of the data are anecdotal. Only two or three labs in the province do the appropriate tests to determine the actual infection.

The correlations detected by this exploratory data analysis may be used to construct more specific hypotheses of actual cause-effect relationships. The number of recorded outbreaks in the province may be too small to really look at correlations. Efforts should therefore be made to pool

data with other States in the Pacific Northwest. However, even data from watersheds without any outbreaks or any significant incidence of waterborne disease are useful since they may support the case against a correlation between land use and waterborne disease. Another option might be to sample the prevalence of asymptomatic *Giardia* in communities on different water supply systems. Any of the above correlations, however, may be obscured by the fact that some communities draw their water supply from multiple sources, weakening the empirical connections between land use and incidence of disease.

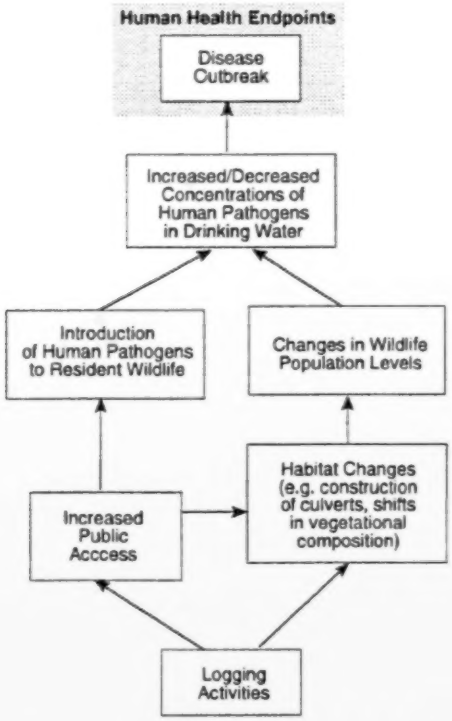
Human Health Endpoints
Disease Outbreak
Increased/Decreased Concentrations of Human Pathogens in Drinking Water
Introduction of Human Pathogens to Resident Wildlife
Changes in Wildlife Population Levels
Habitat Changes (e.g. construction of culverts, shifts in vegetational composition)
Increased Public Acccess
Logging Activities

Figure 6 Indirect effects of logging and recreational access in community watersheds on drinking water quality via wildlife.

2) **Controlled process studies** were identified as a high priority. In particular, studies are needed which provide some understanding of the movement of pathogens in watersheds. There are really two sets of processes of interest: the movement of bacteria and other similar pathogens (e.g., coliforms) and the movement of much longer-lived cysts such as *Giardia* and *Cryptosporidium*. These studies are somewhat analogous to sediment budget studies. We are interested in the sources, pathways for movement (both on the land surface and in water) and sinks of pathogen in watersheds. Unlike sediments, however, most pathogens have a certain lifespan which influences these processes. One of the most important knowledge gaps with

respect to pathogen movement is the relative importance of various pathogen sources and transport pathways in terms of levels at the intake.

An interesting research question, and one with implications for the development of a model is: do *Giardia* or other cysts resemble a particular size class of sediments in their movement through the watershed? If they do, their movement may be modeled using an existing sediment movement model. Closely related to this question is whether pathogen movement is facilitated by sediments - i.e., are pathogens adsorbed to sediments and is that an important mechanism for their movement in a watershed? Other questions include the viable storage time of pathogens in bottom sediments and the effects of temperature on pathogen production and viability.

3) Another important research area is **the cross-infectivity and life cycle of pathogens**, particularly *Giardia* and *Cryptosporidium*. The most important questions are: what wildlife/domestic species carry human pathogens and which pathogens? And what are the relevant risks to humans - i.e., what is the behaviour of these animals (e.g., aquatic-dwelling), to what degree are these pathogens shed to the environment, and in what quantity?

The role of animals in transmitting *Giardia* is still controversial. As an alternative to destructive sampling, trappers may be asked or required to submit samples of the guts of animals they trap for the purposes of studying pathogens in wild animal populations.

Some of these questions are being addressed by the Ministry of Health Giardia Program. The goals and progress of this program are summarized in Appendix G.

5) In addition to smaller-scale process studies, **controlled intensive studies of whole watersheds** were advocated as the best mechanism for determining cause-effect relationships between logging or other activities and pathogen production/export from watersheds. These intensive studies would involve manipulating whole watersheds with a single type of treatment to assess the effects of that treatment relative to an unperturbed control. In addition to the actual treatment, other factors such as wildlife populations would have to be well-controlled. Such studies have proven quite useful in determining the impacts of logging on sediment and water yield from watersheds.

There may be an opportunity to integrate studies into the effects of logging or other treatments on pathogen output with planned studies by the Ministry of Forests to look at effects on physical parameters such as sediment and water yield in the Penticton Creek area. The Penticton Creek Study involves four experimental watersheds which have been monitored/calibrated for 12 years. The Ministry of Forests is planning to add a range and fecal coliform aspect to the study. The Ministry of Health's risk prioritization scheme may be used to select other intensive research sites.

The Ministry of Forests is the only Ministry with a research mandate. Ministry of Health and Ministry of Environment, Lands and Parks might co-operate with MoF in a research program by providing resources for monitoring and analyzing samples.

While intensive studies are preferred, there may also be a role for extensive studies. For example, *Giardia* is not evenly distributed across watersheds in the province. An extensive study to test for the presence or absence of Giardia might also provide useful information. One approach might be to use data/information on human infections to identify regions where Giardia seems to be active (e.g., in a crescent from the Okanagan through lower B.C. to Whistler).

6) We also need a **better means of stratifying watersheds** which is more relevant to health risks such as pathogen movement. For the moment, hydrological stratification of watersheds seems most appropriate. Studies of historical data for correlations and process-oriented studies may reveal additional or more detailed stratifications in the future. Stratifications are particularly important for risk assessments and for producing valid generalizations.

7) **Surveys** on the level and type of recreational activity in community watersheds would be useful, particularly in assessing risk, but also in interpreting correlations in historical and future data sets. The surveys should also gather more specific information about the actual behaviour of watershed users (e.g., sanitary habits).

8) An important research area is the **assessment of the relative costs and benefits** of water treatment (and the health care costs of treating infected individuals) versus the direct control (prevention) of pathogen sources. An important goal of public education is to make the public understand that no access does not necessarily mean no risk. Wildlife can also carry human pathogens into a watershed. Thus, controlled access will not remove the need for any treatment, but it may reduce the level of treatment considered necessary to minimize risks to human health (although that has not yet been demonstrated).

9) Another important area of research is the **development of appropriate indicators** and tools to monitor potential threats to human health. The effectiveness of monitoring fecal coliforms was called into question. While fecal coliforms are used as an indicator of possible contamination with enteric pathogens, they are not sensitive indicators of longer-lived cysts such as *Giardia* and *Cryptosporidium*. *Giardia* itself is costly to sample in the environment and produces a lot of false negatives. Research into appropriate (i.e., cost-effective, sensitive) indicators of *Giardia* contamination is required. This is one of the goals of the Ministry of Health Giardia Program (Appendix G). There might be a role for other indicators of fecal contamination such as *Clostridium*.

There is also a lot of noise in many microbiological parameters; coliform counts are highly variable, both in time and space. The appropriate sampling frequency for fecal coliforms needs to be assessed.

Very basic research is required to support microbiological monitoring efforts. It is important to collect data on both raw and treated water. We also need to undertake continuous sampling of raw water to get some idea of intrinsic variability. Research is required into the relative importance of various sources of intrinsic variability (e.g., temporal, within-site and among-site variability, and ways of reducing those sources of variability (e.g., filter sampling)).

10) **Monitoring** is also required to assess the actual effectiveness of IWMPs. Although most IWMPs specify some post-implementation monitoring program, such monitoring is rarely

undertaken. Workshop participants recommended monitoring changes in raw water quality in the watershed to test if recommended actions are actually working. Of course, analyses of these data will require implementation monitoring to determine whether the prescriptions in the IWMP have actually been implemented. Such information is also necessary for interpreting data regarding disease outbreaks and for assessing the benefits of IWMPs.

We currently do not directly monitor other activities in community watersheds such as recreation, dumping and grazing. We also do not have quantitative information on the effects of logging on these activities (e.g., the increase in recreational use or change in recreational activity following logging). Workshop participants suggested expanding the types of activities/parameters monitored in community watersheds.

There is also a need to catalogue existing monitoring programs, databases and research results both in the province and in neighbouring jurisdictions (i.e., type of research, pathogen of interest, frequency, parameters sampled, geographic extent, temporal extent). The Ministry of Health could take a lead role in this task with partial funding from the Ministry of Forests. Participants suggested setting up an inter-ministry relational database such as the one Ministry of Environment, Lands and Parks is currently developing. A literature view on each of the topics discussed at this workshop should be compiled and distributed.

6.0 Final Plenary: Where do we go from here?

The following is a list of priorities for inter-agency cooperation which were identified during the closing plenary. A more extensive list of recommendations based on an analysis of the entire workshop follows in Section 7.0.

6.1 Information Exchange/Inter-Agency Interaction

Participants suggested a number of opportunities for continued information exchange and cooperation among individuals and agencies:

- Set up an informal Inter-ministry Community Watershed Committee to look at the effectiveness of IWMPs and guidelines and make recommendations regarding future directions in community watershed management. The Committee could also sponsor or produce discussion papers and co-ordinate data collection, data management or research.

  One of the goals of the committee presently working on new guidelines for operating in community watersheds is to establish a procedure to look at the effectiveness of the guidelines. A procedure to monitor, evaluate and improve the guidelines on an ongoing basis will be recommended and hopefully implemented. This will likely involve the establishment of permanent inter-agency committee.

- Both universities and various professional associations (e.g., Registered Professional Foresters, or Friends of Forest Hydrology) offer opportunities for information exchange and coordination among individuals. Specific opportunities are identified further below.

- The guidelines committee held a workshop on March 6, 1993 to receive input from the public through sectorial groups. 1500 questionnaires were also mailed out. A report summarizing the comments/concerns will be available in early June. This will likely be of interest to workshop participants.

- The B.C. Waste and Water Association has subcommittees which often sponsor seminars. The Drinking Water Quality Subcommittee recently sponsored a seminar on the new B.C. Safe Drinking Water Regulation which is available on video tape. A new subcommittee on Community Watersheds could possibly be formed, if enough interest was expressed to the B.C.W.W.A.

- The B.C. Branch of the Canadian Water Resources Association might provide a focal point for interaction and exchange of information. The Branch is starting a newsletter which will be linked to the Washington Branch of the American Water Resources Association. Thus, this Association provides opportunities for information exchange and co-operation among B.C. and other Pacific Northwest States which are experiencing similar problems.

- Some mechanism for exchanging research results and data was identified as a high priority need throughout the workshop. Inter-agency literature reviews and updates might

be circulated in the form of discussion papers on important topics. For example, Vicki Carmichael (Ministry of Health) and Dave Toews (Ministry of Forests) talked about joining their literature reviews on *Giardia*. These reviews might also be used to produce educational materials. For example, some participants talked about developing a prospectus containing common questions and answers regarding *Giardia* in B.C. These materials could be used to communicate what we currently know and do not know about the problem, thus helping to focus public debate.

- The B.C. Subcommittee of Deputy Ministers on Water was identified as one group that might take a lead role in encouraging inter-agency communication and cooperation. The Subcommittee should be briefed on the issues identified in this workshop and encouraged to support workshop follow-up (e.g., recommendations).

6.2 Research

Research was identified as a high priority in many workshop discussions. Only the Ministry of Forests, however, has an explicit research mandate. The Ministry of Health and Ministry of Environment can support drinking water quality research by providing support and resources for data gathering and analysis.

An inter-ministry inventory of current or planned research (and monitoring) efforts regarding this issue is required to support coordination and cooperation. If tied to an assessment of information gaps, this inventory could also be used to support new research projects.

Many participants argued that basic research (e.g., construction and validation of scientific models) must proceed in parallel with applied research in direct support of current management needs (e.g., development of operational/empirical models). In addition to process-oriented research, support is required for management-oriented research such as decision-support tools (e.g., risk assessment tools, workbooks and expert systems to support monitoring efforts).

6.3 Workshop Follow-up

As follow-up to the workshop, a subset of the original workshop participants could meet after delivery of the final report to discuss implementing the recommendations. Future discussions need to look more closely at integration among the subgroups used in this workshop (i.e., sediment, chemistry and health). Many participants argued that something operational should eventually come out of these discussions (e.g., a decision-support tool). At a minimum, a simple conceptual model might be constructed which integrates across all of the stressors and impact endpoints, and summarizes the relationships (impact pathways) discussed at the workshop.

In particular, the approach of the chemistry subgroup might be summarized in the form of a concise handbook for water managers so that they can see what should be considered in watershed management. The approach used by the chemistry subgroup might provide a template for systematically assessing what processes/activities are most important in a specific watershed.

Finally, some participants suggested that the Water Management Division of the Ministry of Environment, Lands and Parks might produce a formal discussion paper including a review of major drinking water quality issues in the province and suggesting a vision of how to proceed to address these issues. This report should provide much of the raw material for such a discussion paper, supplemented with more specific references and initiatives.

7.0 General Recommendations and Directions

The following set of recommendations was produced through a synthesis and analysis of the workshop discussions summarized in preceding sections. They are more broad than the specific recommendations found in each of the subgroup summaries. Most of the recommendations below integrate across all subgroup discussions or pertain to watershed management in general.

One unifying theme which quickly emerged from this synthesis was the need for a *systems approach* in addressing concerns regarding forestry-drinking water quality interactions. A systems approach is already employed by the Ministry of Forests in its sediment budget studies. The approach and conceptual model developed by the chemical subgroup embodies many of the principles of a systems approach; their work will hopefully be carried into future research and monitoring activities. The systems perspective was least well-developed from the perspective of human health; this may be due to both jurisdictional considerations (i.e., the Ministry of Health's mandate begins at the intake) and the need for very basic research into pathogen movement in watersheds. Many of the recommendations from the health subgroup, however, support a systems approach to assessing and managing human health risks.

Underlying many of the following recommendations, then, is the need to support and expand a systems approach to managing community watersheds. This is embodied, for example, in recommendations concerning greater inter-agency integration and cooperation, more watershed-scale research and monitoring, more holistic decision support tools, and greater emphasis on public/user education. Specific recommendations are:

Institutional Guidance:

1) **Produce a formal discussion paper including a review of major drinking water quality issues in community watersheds in B.C. and outlining a vision of how to proceed in addressing these issues.**

   The Ministry of Environment, Lands and Parks (Water Management Branch), the Ministry of Forests (Research and Integrated Resource Management Branches), and the Ministry of Health (Public Safety) should jointly write this discussion paper. This report should provide much of the raw material for such a paper, supplemented with more specific references and initiatives.

2) **Establish an informal inter-agency community watershed group with a much broader focus than the panels set up as part of the Integrated Watershed Management Planning (IWMP) processes in specific watersheds.**

   This group should be formed of representatives from the Ministry of Environment, Lands and Parks, the Ministry of Forests, the Ministry of Health, and user groups such as forest companies and water districts (e.g., the inter-agency committee revising community watershed guidelines with the addition of user groups). Its purpose would be to coordinate

communication and follow-up on the recommendations from this workshop (including the discussion paper proposed above). This group might also stimulate eventual formation of a more formal group. The group might prepare a presentation/briefing for the B.C. Subcommittee on Water to encourage a more formal approach to community watershed management and research. The group might also explore other avenues for information exchange/integration such as the B.C. Branch of the Canadian Water Resources Association or the B.C. Waste and Water Association.

Conceptual/Scientific Models:

3) **Develop an integrated, systems-level conceptual model of forestry-drinking water quality interactions that includes chemistry, sediment and health.**

Such a conceptual model would help guide research, monitoring and modelling efforts. Many of the components of a systems-level conceptual model are embodied in this, or other readily available reports. Literature reviews are necessary to supplement and/or expand the impact hypotheses identified here. More attention must also be given to the integration of sediment, chemical and human health endpoints. Economic endpoints might also be considered, either in relation to physical, chemical or health endpoints (i.e., attach socioeconomic values to these endpoints) or as endpoints themselves (e.g., the economic trade-offs between controlling land use and expanding water treatment). The need to integrate socioeconomic considerations into risk assessment, monitoring, research and management was raised in numerous discussions.

4) **Use this model as a template for developing conceptual systems-level models of interactions between drinking water quality and other management activities in community watersheds (e.g., agriculture, grazing or urbanization).**

Although important in terms of current public opinion, forestry is clearly only one potential stressor on drinking water quality in community watersheds. Many of the suggestions embodied in this report, and the systems approach used by each of the workshop subgroups, could serve as a framework for assessing other watershed activities. Eventually, a much larger conceptual model integrating among drinking water quality endpoints and a much wider range of stressors might be developed. Such a model would provide a framework for monitoring, modelling and development of decision support tools (e.g., risk assessment).

5) **Develop scientific quantitative models of processes/impact pathways to help synthesize data and improve understanding.**

Detailed scientific models are useful for increasing our understanding of how human activities affect water quality. Sediment budget models are already being quantified in a number of watersheds around the province. Our understanding of watershed-level chemical processes is also increasing to the point where more rigorous quantitative models of particular processes or impact pathways might be developed. Our understanding

of many of the linkages to health is still rudimentary, particularly in terms of human pathogens; more basic research and monitoring is required to support model development.

Caveats: Before investing time and money in developing quantitative models, a more detailed assessment of user needs (e.g., small water districts which were not represented at the workshop) is required. This information could also be used to develop an appropriate user interface if a model was developed. Furthermore, in using quantitative models for making management decisions, special attention must be paid to impacts which have not yet been quantified due to a lack of understanding or data, but which may nevertheless be important. What we know should be balanced (perhaps through risk assessment) by what we do not know.

Research:

6) **Increase research into human pathogens, including their sources and movement in watersheds and development of appropriate indicators.**

Basic research is the highest priority in addressing most human health concerns surrounding forestry and other activities in community watersheds. Specific research recommendations are summarized in Section 5.3.2. Inter-agency cooperation is necessary since the Ministry of Forests is the only government agency in this area which has an explicit research mandate. Opportunities to examine human health concerns in current or planned intensive (whole-watershed) studies should be explored.

Data Collection:

7) **An approach to regionalization and/or stratification of watersheds is required to support generalization of research results, risk assessments, and development of monitoring guidelines.**

All three subgroups identified the need for an appropriate regionalization/stratification of watersheds upon which to base generalizations and risk assessments regarding the impacts of management activities on chemical water quality, sediment yield, and human health. Such a regionalization/stratification is not only useful for reporting research and monitoring results, but also in developing guidelines and educating the general public (e.g., regarding natural water quality). Much effort has gone into hydrogeoclimatic stratification for sediment budgets. More work needs to be done on assessing the appropriateness of these stratifications for chemical and microbiological parameters.

8) **Promote better inter-agency coordination of research and monitoring at the small number of intensive research sites around the province.**

Coordination is required to ensure that the information necessary for improving assessment activities for drinking water quality is both gathered and exchanged. Reporting systems for episodic events (e.g., landslides, disease outbreaks, algal blooms, etc.) also

need to be improved to ensure the appropriate information on water quality impacts is gathered.

9) **Develop concise, understandable guidelines for monitoring sediment, chemistry, and health endpoints in community watersheds.**

Inter-agency guidelines should be developed to support intensive or extensive drinking water quality monitoring efforts. Monitoring guidelines were recently developed for evaluating effects of forestry activities on streams in the Pacific Northwest and Alaska (MacDonald et al. 1991). These might be tailored more specifically to community watersheds, possibly dealing with a wider range of watershed activities. These guidelines could eventually be used to develop an expert system to support decision-making in smaller watersheds with limited time and resources. One example of such a system is the Parameter Selection System for Streams in Forested Areas developed by the EPA (MacDonald et al. 1991).

Guidelines might also be considered to coordinate resource inventory methods among agencies, jurisdictions and or land owners in community watersheds. A major barrier to model development is the lack of congruent data regarding watershed resources, land use, etc., particularly in community watersheds with multiple land owners.

Decision Support Tools:

10) **Develop risk assessment guidelines for community watersheds. Develop better decision support tools for the numerous small, data-poor community watersheds in the province.**

The development of guidelines and tools for risk assessment was seen as a high priority in most workshop discussions. Risk should be assessed from the perspective of all three groups of endpoints (chemical, sediment and health), and include socioeconomic considerations. Hence, risk assessment should be integrated within a cost-benefit framework which includes both monetary and non-monetary values. Increased understanding will never remove all of the uncertainty regarding forestry-drinking water quality since many of the risks are associated with stochastic episodic events (e.g., storms).

The approach used by the chemistry subgroup in this workshop might be summarized in the form of a concise handbook for water managers. Their approach may provide a template for systematically assessing what processes/activities are most important in a specific watershed.

Information Exchange:

11) **Prepare and circulate discussion papers documenting our current understanding of the various impact pathways/processes affecting drinking water quality in community watersheds.**

This workshop provided a lot of opportunity for sharing information and ideas. Most participants felt that other mechanisms for exchanging information/knowledge among a wider audience should be explored. The conceptual models mentioned above could be used to organize discussion papers and literature reviews which could then be circulated as discussion papers. This information could also be used to eventually produce educational materials.

Education:

12) Education of both the public and watershed users (e.g., loggers, recreationalists) is an integral part of overall water quality management in community watersheds.

Public education is required to address unrealistic expectations of water quality, such as the belief that no access to a watershed means no risk of water-borne disease, or the perception that water from every community watershed is naturally low in turbidity or high in terms of chemical quality. Education efforts would be supported by many of the monitoring/research efforts recommended above to catalogue baseline water quality, determine trends over time and test linkages between watershed activities and drinking water quality. User education is required to modify the behaviours or user groups (e.g., sanitary habits) such as loggers, recreationists and range managers. The discussion papers documenting current understanding regarding forestry-drinking water quality interactions could be simplified and used in educational materials (e.g., "Ten common questions and answers about *Giardia*"). The conceptual models developed above might also be used to produce computer games (models) which illustrate some of the suspected trade-offs among management decisions. Such models would be used merely for educational purposes rather than to support actual management decisions.

8.0 Background Literature

This is not an exhaustive bibliography. Many of the references were provided by Vicki Carmichael in the Ministry of Health. Some of the references are incomplete. Additional references are available in Pierre Beaudry's paper in Appendix F.

Adams, P.W. and W.R. Stack. 1989. Streamwater quality after logging in southwest Oregon. Project Complete Report (Supplement Number PNW 87-400) to the USDA Forest Service. Pacific Northwest Research Station, Portland, Oregon.

Adams, P.W. and R.L. Taylor. 1986. Red alder leaf litter and stream water quality in western Oregon. Water Resour. Bull. 22(4): 629-635.

Adams, P.W., R.L. Beschta, and H.A. Froehlich. 1988. Mountain logging near streams: opportunities and challenges. In: Proceedings, International Mountain Logging and Pacific Northwest Skyline Symposium, Dec. 1988. Portland Oregon State University, College of Forestry, Corvallis, Oregon, pp. 153-162.

Aukerman, R. and W.T. Springer. 1976. Effects of Recreation of Water Quality in Wildlands. Eisenhower Consortium Bulletin 2. Eisenhower Consortium for Western Environmental Forestry Research.

BC Committee for Safe Drinking Water. 1991. Safe Drinking Water for British Columbia: Background Report. Cot. 4.

Beasley, R.S., A.B. Granillo, and V. Zillmer. 1986. Sediment losses from forest management: mechanical vs. chemical site preparation after clearcutting. J. Environ. Qual. 15(4): 413-416.

Beaudry, P. 1992. *A review of sediment monitoring strategies for assessing the impacts of forestry related activities*. B.C. Forest Service, Forest Sciences Section, Smithers, B.C.

Beaulac, M.N. and K.H. Reckhow. 1982. An examination of land use - nutrient export relationships. Water Resour. Bull. xx: 1013-1023.

Beeh, J. 1992. *Cryptosporidium* Literature Review. Prepared for the Washington State Department of Health, Environmental Health Programs, Drinking Water Program.

Beschta, R.L. 1978. Long-term patterns of sediment production following road construction and logging in the Oregon coast range. Water Resour. Res. 14(6): 1101-1106.

Beschta, R.L. and R.L. Taylor. 1988. Stream temperature increases and land use in a forested Oregon watershed. Water Resour. Bull. 24(1): 19-24.

Beschta, R.L. et al. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. In: E.O. Salo and T.W. Cundy (eds.). Streamside Management: Forestry and Fishery Interactions. College of Forest Resources, University of Washington, and Institute of Forest Resources. Contribution No. 57. Chapt. 6, pp. 191-224.

Brigham, A.P. 1966. Recreation use of watersheds -- operator's view. J. Amer. Water Work Assn. October(1966): 1260-1263.

Brooks, K.N., et al. 1991. Hydrology and Management of Watersheds. Iowa State University Press, Ames, Iowa.

Brown, G.W. 1969. Predicting temperature of small streams. Water Resour. Res. 5(1): 68-75.

Brown, G.W. 1980. Forestry and Water Quality. Oregon State University Book Store, Inc. Corvallis, Oregon.

Brown, G.W. and R.L. Beschta. 1985. The art of managing water. J. For. 83(10): 604-615.

Brown, G.W. and J.T. Krygier. 1970. Effects of clear-cutting on stream temperature. Water Resour. Res. 6(4): 1133-1139.

Brown, G.W. and J.T. Krygier. 1971. Clear-cut logging and sediment production in the Oregon coast range. Water Resour. Res. 7(5): 1189-1198.

Brown, G.W., A.R. Gahler, and R.B. Marston. 1973. Nutrient losses after clear-cut logging and slash burning in the Oregon coast range. Water Resour. Res. 9(5): 1450-1453.

Brown, G.W., R.M. Rice, and R.B. Thomas. 1976. Water pollution control and forestry. J. For. 74(6): 342-345.

Carswell, J.K., J.M. Symons, and G.G. Robeck. 1969. Research on recreational use of watersheds and reservoirs. J. Amer. Water Work Assn. June(1969): 297-304.

Castlegar (SNS). 1991. The Kootenays, a nice place to visit, but don't drink the water. Nelson Daily News, Nov. 21.

Chang, L.H., C.T. Hunsaker, and J.D. Draves. 1992. Recent research on effects of climate change on water resources. xx 28(2): 273-286.

Chichester, F.W., R.W. Van Keuren, and J.L. McGuinness. 1979. Hydrology and chemical quality of flow from small pastured watersheds: II. Chemical quality. J. Environ. Qual. 8(2): 167-171.

Clark, M.J.R. (ed.). 1992. Status Report of the QA Work Group: A Report of the Quality Assurance Work Group. Canada-British Columbia Water Quality Monitoring Agreement.

Cobourn, J. 1989. Is cumulative effects analysis coming of age? *Journal of Soil and Water*

Conservation July-August.

Craun G.F. 1988. Surface water supplies and health. J. Amer. Water Work Assn. February(1988): 40-52.

Crippen Consultants. 1990. Municipal Water Supply Issue in British Columbia. British Columbia Round Table on the Environment and the Economy.

Day, J.C. and J.A. Affum. 1990. Toward Sustainable Water Planning and Management in British Columbia. Prepared for the British Columbia Round Table on the Environment and the Economy.

De Vries, J. and T.L. Chow. 1978. Hydrologic behaviour of a forested mountain soil in coastal British Columbia. Water Resour. Res. 14(5): 935-942.

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company, San Francisco, CA.

Economic and Engineering Services, Inc. 1990. Water Quality Improvement Program, Greater Vancouver Water District Primary Disinfectant: draft final report.

Economic and Engineering Services, Inc. 1990. Water Quality Improvement Program, Greater Vancouver Water District Primary Disinfectant: final summary report.

Environmental Consulting Division. 1992. Greater Victoria Water District Land Use Technical Review: Summary Report.

Enwright M. and A. Diem. n.d. Clearcuts = flooding. Interview between M. Enwright of the CBC and Professor A. Diem of the Geography Department of the University of Waterloo.

Erlandsen S.L. and W.J. Bemrick. 1988. Waterborne giardiasis: sources of giardis cysts and evidence pertaining to their implication in human infection. In: P.M. Wallis and B.R. Hammond (eds.). Advances in *Giardia* Research. University of Calgary Press, Calgary, Alberta, pp. 227-236.

Feller, M.C. and J.P. Kimmins. 1984. Effects of clearcutting and slash burning on streamwater chemistry and watershed nutrient budgets in southwestern British Columbia. *Water Resources Research* 20(1): 29-40.

Fransolet, G. et al. 1988. The role of bicarbonate in bacterial growth in oligotrophic waters. J. Amer. Water Work Assn. November(1988): 57-61.

Fraser G.G. and K.R. Cooke. 1991. Endemic giardiasis and municipal water supply. Am. J. Public Health 81(6): 760-762.

Fredriksen, R.L. and R.D. Harr. 1979. Soil, vegetation and watershed management. In: P.E. Heilman, H.W. Anderson, and D.M. Baumgartner (eds.). Forest Soils of the Douglas-Fir Region. Washington State University, Cooperative Extension. Chapt. 13, pp. 231-260.

Fredriksen, R.L., D.G. Moore, and L.A. Norris. 1973. The impact of timber harvest, fertilization and herbicide treatment on streamwater quality in western Oregon and Washington. In: Proceeding of the Fourth North American Forest Soils Conference.

Geldreich, E.E. 19xx. Applying bacteriological parameters to recreational water quality. J. Amer. Water Work Assn. xx: 113-120.

Gluns, D. R. and D. A. A. Toews. 1989. Effect of a major wildfire on water quality in southeastern British Columbia. *Headwaters Hydrology* (American Water Resources Association) June: 487-499.

Goldin A. and L.M. Lavkulich. 1988. Historical land clearing in the Fraser lowland of British Columbia and Washington State: II. Effects on soil variability. Soil Sci. Soc. Amer. J. 52: 473-477.

Harr, R.D. and E.M. McCorison. 1979. Initial effects of clearcut logging on size and timing of peak flows in a small watershed in western Oregon. Water Resour. Res. 15(1): 90-94.

Harr, R.D., W.C. Harper, and J.T. Krygier. 1975. Changes in storm hydrographs after road building and clear-cutting in the Oregon coast range. Water Resour. Res. 11(3): 436-444.

Hetherington, E.D. 1987. The importance of forests in the hydrological regime. In: M.C. Healey and R.R. Wallace (eds.). *Canadian Aquatic Resources*. Canadian Bulletin of Fisheries and Aquatic Sciences 215. The Rawson Academy of Aquatic Science, Department of Fisheries and Oceans, Ottawa, Ontario. Chapt. 7, pp. 179-211.

Hewlett, J.D. and J.D. Helvey. 1970. Effects of forest clear-felling on the storm hydrography. Water Resour. Res. 6(3): 768-782.

Hicks, B.J., R.L. Beschta, and R.D. Harr. 1991. Long-term changes in streamflow flowing logging in western Oregon and associated fisheries implications. Water Resour. Bull. 27(2): 217-226.

Hoehn, R.C. n.d. Biological causes of tastes and odours in drinking water supplies.

Hogan and Wilford. 1989. A sediment transfer hazard classification system: linking erosion to fish habitat. In Proceedings of Watershed '89, E.B. Alexander, ed. USDA Forest Service, Alaska Region: Juneau, AK.

Hohnson, D.W. et al. 1988. The effects of leaching and whole-tree harvesting on cation budgets of several forests. J. Environ. Qual. 17(3): 418-424.

Hornbeck J.W. 1973. Storm flow from hardwood-forested and cleared watersheds in New Hampshire. Water Resour. Res. 9(2): 346-354.

Hornbeck, J.W., and W. Kropelin. 1982. Nutrient removal and leaching from a whole-tree harvest of northern hardwoods. J. Environ. Qual. 11(2): 309-315.

Hornbeck, J.W., R.S. Pierce, and C.A. Federer. 1970. Streamflow changes after forest clearing in New England. Water Resour. Res. 6(4): 1124-1132.

Hutton, R.L. 1991. *Giardia*, logging, roads, drinking water and your health. The Kootenay Weekly Exp., Nov. 6.

Hutton, R.L. 1991. Nelson doctors oppose activity in watershed. Nelson Daily News, Dec. 4.

Hutton, R.L. 1992. Benefits of logging should outweigh possible costs -- Letters to the Editor. Nelson Daily News, Jan. 29.

Irwin G.S. 1991. *Giardia* and *Cryptosporidium*: risk of waterborne infection in Greater Victoria. Report to the Administrative Board of the Greater Victoria Water District, Greater Victoria Water District.

Johnson, M.G. and R.L. Beschta. Logging, infiltration capacity and surface erodibility in western Oregon. J. For. 78(6): 334-337

Kasianchuk, D.A. 1992. A Discussion Paper on the Project of Stewardship of the Water of British Columbia: Second Draft. Water Management Division, BC Ministry of Environment, Lands and Parks.

Kitner, J.C. and R.D. Donner. 1986. Criteria to be considered in the regulatory approval of unfiltered surface water system.

Lamoreaux, H. 1992. Medical experts on forestry need scotoma corrected -- Letters to the Editor. Nelson Daily News, Jan. 9.

Lawrence, G.B., R.D. Fuller, and C.T. Driscoll. 1987. Release of aluminum following whole-tree harvesting at the Hubbard Brook experimental forest, New Hampshire. J. Environ. Qual. 16(4): 383-390.

Lee, R.D., J.M. Symons, and G.G. Robeck. 1970. Watershed human-use level and water quality. J. Amer. Water Work Assn. xx: 412-422.

MacDonald, L.H., A.W. Smart, and R.C. Wissmar. 1991. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska. Environmental Protection Agency, Seattle, Washington. EPA 910/9-91-001.

Marr, B.E. and R.J. Buchanan. 1971. Some water quality aspects of forested watershed management: a review.

McClurkin, D.C. et al. 1985. Water quality effects of clearcutting upper coastal plain loblolly pine plantations. J. Environ. Qual. 14(3): 329-332.

McClurkin, D.C., P.D. Duffy, and N.S. Nelson. 1987. Changes in forest floor and water quality following thinning and clearcutting of 20-year-old pine. J. Environ. Qual. 16(3): 237-241.

McLachlan, D.R.C. et al. 1991. Would decreased aluminum ingestion reduce the incidence of Alzheimer's disease? Can. Med. Assn. J. 145(7): 793-829, 1534.

McNamee, P. J., M.L. Jones, L. A. Greig, C.H.R. Wedeles, D. R. Marmorek and L.P. Rattie. 1987. Effects Monitoring for Resource Protection Guidelines in Ontario - Final Report. Prepared by ESSA Ltd. for the Ontario Ministry of Natural Resources.

McNeely, R.N., V.P. Neimanis, and L. Dwyer. 1979. Water Quality Sourcebook: A Guide to Water Quality Parameters. Inland Water Directorate, Pacific and Yukon Region, Vancouver, B.C., Environment Canada.

Miller E.L., R.S. Beasley, and E.R. Lawson. 1988. Forest harvest and site preparation effects on erosion and sedimentation in the Quachita Mountains. J. Environ. Qual. 17(2): 219-225.

Miller E.L., R.S. Beasley, and E.R. Lawson. 1988. Forest harvest and site preparation effects on stormflow and peakflow of ephemeral streams in the Quachita Mountains. J. Environ. Qual. 17(2): 212-218.

Miltner, R.J. et al. 1989. Treatment of seasonal pesticides in surface waters. J. Amer. Water Work Assn. January(1989): 43-52.

Ministry of Environment and Ministry of Forests. 1992. Summary Report on the June 1992 Slope Failure at Donna Creek, near Mackenzie, British Columbia. Donna Creek Technical Investigative Team.

Najari, M. 1991. The GVWD: A House of Cards? A Critical Review of Logging Activity in Victoria's Municipal Watershed, 1924-1991. Sierra Club of Canada, Victoria Group.

Nakos, G. and A. Vouzaras. 1988. Budgets of selected cations and anions in two forested experimental watersheds in central Greece. Forest Ecol. Manage. 24: 85-95.

Nordin, R.N. 1985. Water Quality Criteria for Nutrients and Algae. Water Management Branch, Ministry of Environment, Province of British Columbia.

Ongerth, J.E. 1989. *Giardia* cyst concentrations in river water. J. Amer. Water Work Assn. September(1989): 81-86.

Pacha, R.E. 1981. Effects of dispersed recreation on water quality. In: D.M. Baumgartner (ed.).

Interior West Watershed Management. Washington State University, Cooperative Extension, pp. 161-168.

Ponce, S.L. 1974. The biochemical oxygen demand of finely divided logging debris in stream water. Water Resour. Res. 10(5): 983-988.

Reynolds, P.E. (ed.). 1989. Proceedings of the Carnation Creek Herbicide Workshop. Economic and Regional Development Agreement, B.C. Canada.

Rishel, G.B. et al. 1982. Seasonal stream temperature changes following forest harvesting. J. Environ. Qual. 11(1): 112-116.

Robbins, R.W., J.L. Glicker, D.M. Bloem, and B.M. Niss. 1991. Effective Watershed Management for Surface Water Supplies. AWWA Research Foundation and American Water Works Association, Portland, Oregon.

Rose, J.B. 1988. Occurrence and significance of *cryptosporidium* in water. J. Amer. Water Work Assn. 80: 53-58.

Rose, J.B., C.N. Haas, and S. Regli. 1991. Risk assessment and control of waterborne giardiasis. Am. J. Public Health 81(6): 709-713.

Rothwell, R.L. 1978. Watershed Management Guidelines for Logging and Road Construction in Alberta. Northern Forest Research Centre, Canadian Forestry Service, Fisheries and Environment Canada.

Ryan, S.E. and G.E. Grant. 1991. Downstream effects of timber harvesting on channel morphology in Elk River Basin, Oregon. J. Environ. Qual. 20: 60-72.

Sidle, R.C. and J.W. Hornbeck. 1991. Cumulative effects: a broader approach to water quality research. J. Soil Water Conserv. July/August(1991): 268-271.

Skinner, Q.D. et al. 1974. Effect of summer use of a mountain watershed on bacterial water quality. J. Environ. Qual. 3(4): 329-335.

Smith, A.L. et al. 1985. A Water Quality Study of the Akamina-Kishinena Watershed and Other Tributaries to the Flathead River in British Columbia Subjected to Logging. Inland Waters Directorate, Pacific and Yukon Region, Vancouver, B.C., Environment Canada.

Smith, A.L. et al. 1985. A Water Quality Study of the Akamina-Kishinena Watershed and Other Tributaries to the Flathead River in British Columbia Subjected to Logging: Data report. Inland Waters Directorate, Pacific and Yukon Region, Vancouver, B.C., Environment Canada.

Swanson, R.H. et al. 1986. Hydrologic effects of clear-cutting at Marmot Creek and Streeter Watersheds, Alberta. Northern Forestry Centre and Canadian Forestry Service, Edmonton, Alberta. Info. Rep. NOR-X-278.

Toews, D.A.A. and M.J. Brownlee. 19xx. A Handbook for Fish Habitat, Protection on Forest Lands in British Columbia. Fisheries and Oceans, Government of Canada.

Toews, D. and D. Wilford. 1978. Watershed Management Considerations for Operational Planning on T.F.L. #39 (Blk 6A) Graham Island. Fisheries and Marine Services, Department of Fisheries and Ocean, Manuscript Report No. 1473.

Trimble, S.W., F.H. Weirich, and B.L. Hoag. 1987. Reforestation and the reduction of water yield on the southern piedmont since circa 1940. Water Resour. Res. 23(3): 425-437.

Tripp, D., A. Nixon, and R. Dunlop. 1992. The application and effectiveness of the Coastal Fisheries Forestry Guidelines in selected cut blocks on Vancouver Island. D. Tripp Biological Consultants, Nanaimo, B.C.

Troendle, C.A. and R.M. King. 1985. The effects of timber harvest on the Fool Creek Watershed, 30 years later. Water Resour. Res. 21(12): 1915-1922.

Van Lear, D.H. et al. 1985. Sediment and nutrient export in runoff from burned and harvested pine watershedsin the South Carolina piedmont. J. Environ. Qual. 14(2): 169-174.

Wallis, P.M. and B.R. Hammond (eds.). 1988. Advances in *Giardia* Research. The University of Calgary Press, Calgary, Alberta.

Watershed Control Program. U.S. Surface Water Treatment Rule. 1992.

West, P.A. 1991. Human pathogenic viruses and parasites: emerging pathogens in the water cycle. J. Appl. Bacteriol. Symp. Suppl. 70: 107S-114S.

Willey, B.R. 19xx. *Giardia* Presence in Treated Waters. CWC-HDR, Inc.

Wright, K.A., K.H. Sendek, R.M. Rice, and R.B. Thomas. 1990. Logging effects on streamflow: storm runoff at Caspar Creek in northwest California. Water Resour. Res. 26(7): 1657-1667.

Wolfe, M.S. 1992. Giardiasis. Clin. Microbiol. Rev. 5(1): 93-100.

Ziemer, R.R., J. Lewis, R.M. Rice and T.E. Lisle. 1991. Modelling the cumulative watershed effects of forest management strategies. *J. Environ. Qual.* 20: 36-42.

Zimmerman, R. 1992. A letter to the Greater Victoria Water District Board members. Sept. 30.

Appendix A
Agenda

Tuesday - March 2

Opening Plenary:

9:00 a.m. Workshop Welcome and Participant Introductions - Rick Nordin, MELP

9:10 a.m. Review of Workshop Objectives & Agenda - Trent Berry, ESSA Ltd.

9:15 a.m. Presentations: Overview of issues - Hydrology, Dave Toews, MoF
Sediment, Pierre Beaudry, MoF
Chemistry, Rick Nordin, MELP
Health, Barry Willoughby and Vicki Carmichael, MoH

10:45 a.m. Break

11:00 a.m. Presentation: Sediment-Water Chemistry Interactions in the Capilano Watershed, GVRD - Chris Perrin, Limnotech

Questions & Discussion

12:00 p.m. Lunch

1:00 p.m. Presentation: Impact hypotheses, analytical tools, and their application to watershed management - Tim Webb, ESSA Ltd.

Questions & Discussion

1:30 p.m. Plenary Discussion

Tasks:

- Problem definition and bounding
- Identify needs and players
- Evaluate scales, and spatial/temporal resolutions of interest
- Generate a list of relevant forestry-related activities
- Identify more specific impact end-points

2:15 p.m. Subgroup Discussions

Tasks:

- Formulate impact hypotheses describing the processes and pathways linking each forestry-related activity to specific endpoints
- Discuss linkages with other subgroups

3:30 p.m. Break

3:45 p.m. Subgroup cont'd

5:00 p.m. Supper

Wednesday - March 3

8: 30 a.m. Subgroup sessions cont'd

Tasks:
- Finish formulating impact hypotheses
- Identify existing data sets and research programs which might support model development
- Identify knowledge gaps
- Identify data needs
- Identify research, monitoring and modelling priorities and recommendations vis-a-vis subgroup

12:00 p.m. Lunch

1:00 p.m. Subgroup discussions cont'd

Tasks:
- Finish outstanding tasks from morning session
- Discuss inter-agency co-operation: opportunities and needs

2: 45 p.m. Break

Closing Plenary

3:00 p.m. Facilitators present results of subgroup discussions

3:45 p.m. Plenary discussion: Inter-agency cooperation: priorities and recommendations
Where do we go from here?

4:30 p.m. Closing

Appendix B
Workshop Participants

Forestry Drinking Water Quality Workshop, March 2-3, 1993

Name	Agency	Tel/Fax	Subgroup
Bob Askin	MacMillan Bloedel Ltd. Woodland Services Division 65 Front Street Nanaimo, BC V9R 5H9	T 755-3456 F 755-3550	Sediment
Pierre Beaudry	Ministry of Forests Prince Rupert Forest Region Bag 5000, 3726 Alfred Ave. Smithers, BC V0J 2N0	T 847-7429 F 847-7217	Sediment
Trent Berry	ESSA Ltd. 300 - 1765 W. 8th Ave. Vancouver, BC V6J 5C6	T 733-2996 F 733-4657	Health
Dwain Boyer	BC MELP Water Management Division Kootenay Regional Headquarters 617 Vernon St. Nelson, BC V1L 4E9	T 354-6372 F 354-6332	Sediment
George Butcher	BC MELP Water Management Division 765 Broughton St. Victoria, BC V8V 1X4	T 387- 9515 F 356-8298	Chemistry
Valerie Cameron	Greater Vancouver Water District 4330 Kingsway Burnaby, BC V5H 4G8	T 432-6200 F	Sediment
Vicki Carmichael	Ministry of Health Public Health Protection Lower Main 1520 Blanshard St. Victoria, BC V8W 3C8	T 387-2590 F 356-8850	Health
Reid Carter	Fletcher Challenge Ltd. P.O. Box 10058 Pacific Centre BC Vancouver, BC V7Y 1J7	T 654-4990 F 654-4394	Chemistry

Name	Agency	Tel/Fax	Subgroup
Allan Chapman	BC MELP Water Management Division 765 Broughton St. Victoria, BC V8V 1X4	T 953-3835 F 387-6751	Health
Steve Chatwin	Ministry of Forests Forest Science Research Br. 31 Bastion Square Victoria, BC V8W 3E7	T 387-5887 F 387-0046	Health
Mike Church	University of British Columbia Geography Department Vancouver BC V6T 1W5	T 822-2727 F 822-6959	Sediment
Mike Feller	University of British Columbia Faculty of Forestry 270-2357 Main Mall Vancouver, BC V6T 1Z4	T 822-2727 F 822-9102	Chemistry
Eugene Hetherington	Forestry Canada Pacific Centre 506 W. Burnside Victoria, BC V8Z 1M5	T 363-0600 F 363-0775	Chemistry
Dan Hogan	Ministry of Forest Vancouver Forest Region 4595 Canada Way Burnaby, BC V5G 4L9	T 387-5887 F 660-7778	Sediment
Rob Hudson	Ministry of Forests Vancouver Forest Region 4595 Canada Way Burnaby, BC V5G 4L9	T 660-7528 F 660-7778	Chemistry
Stewart Irwin	Greater Victoria Water District 479 Island Hwy. Victoria, BC V9B 1H7	T 474-9600 F 474-4012	Chemistry
Bob Jones	Greater Vancouver Water District 4330 Kingsway Burnaby, BC V5H 4G8	T 451-6001 F 451-6019	Chemistry

Name	Agency	Tel/Fax	Subgroup
Gordon Joyce	Greater Victoria Water District 479 Island Hwy. Victoria, BC V9B 1H7	T 474-9600 F 474-4012	Sediment
Ben Kangasaiemi	BC MELP Water Quality Branch 765 Broughton St. Victoria, BC V8V 1X4	T 387-9493 F 356-8298	Sediment
Joyce Michaud	Ministry of Health Box 670 Ladysmith, BC V0R 2E0	T 245-7119 F 245-3993	Health
Rick Nordin	BC MELP Water Management Divison 765 Broughton St. Victoria, BC V8V 1X4	T 387-9517 F 356-8298	Chemistry
Chris Perrin	Limnotek Research & Development Inc. 4035 West 14 Ave. Vancouver, BC V6R 2X3	T 222-3546 F 222-3577	Chemistry
Larry Pommen	BC MELP Water Management Divison 765 Broughton St. Victoria, BC V8V 1X4	T 387-9516 F 356-8298	Sediment
Dave Toews	Ministry of Forests Nelson Forest Region 518 Lake St. Nelson, BC V1L 4V6	T 354-6284 F 354-6254	Health
Pat Warrington	BC MELP Water Quality Branch 765 Broughton St. Victoria, BC V8V 1X4	T 387-9513 F 356-8290	Health
Tim Webb	ESSA Ltd. 300 - 1765 W. 8th Ave. Vancouver, BC V6J 5C6	T 733-2996 F 733-4657	Sediment
Bob Willington	Fletcher Challenge Canada Limited PO Box 130 Crofton, BC V0R 1R0	T 246-9332 F 246-9644	Sediment

Name	Agency	Tel/Fax	Subgroup
Barry Willoughby	Ministry of Health Public Health Protection Lower Main 1520 Broughton St. Victoria, BC V8W 3C8	T. 387-2696 F 356-8850	Health

Appendix C
Case Study: An Integrated Watershed Management Planning Process on Eastern Vancouver Island

The purpose of the following case study is to provide an illustration of the differing perspectives and types of potential conflicts confronted in IWMP. It provides context for discussions about management needs and constraints. The watershed used for this case study is currently undergoing an IWMP process. Out of respect for participants in the process, references to individuals, place names, etc. have been removed.

Context:

- A small second-growth watershed on eastern Vancouver Island
- The recently initiated IWMP process was precipitated by one recent cut block

Land Ownership:

- There are 4 major land owners
- There are three lakes in the planning area; a nearby town owns the land (about 5% of the planning area) immediately around the lakes which are its primary water source; three other water districts also rely on the watersheds for part of their water supply
- About 57% of the planning area is owned by a private forest company as part of a Tree Farm License (Schedule A Land)
- Another private forest company owns about 7% of the land classified as managed under forest land under the BC Assessment Act
- The Ministry of Forests is responsible for integrated resource management of 31% of the planning area as provincial forest

Water Licenses:

- There are eleven licensed water users in the planning area

Additional Resource Uses:

- There is an active licensed trapper in the planning area
- There are two mineral claims in the planning area and future exploration can be expected
- No designated historic sites but avoidance of potentially significant sites is desired

IWMP Committee:

- Co-chaired by Ministry of Forests and Ministry of Environment, Lands and Parks
- Two private forest companies
- Archaeology Branch, Ministry of Tourism and Ministry Responsible for Culture
- Ministry of Health
- Two municipalities (one has not yet submitted comments to committee) and one regional district
- Fish and Wildlife Branch
- Department of Fisheries and Oceans
- Ministry of Energy Mines and Petroleum Resources

- Four participants "representative" of the public (water and watershed users)
- Local Native Band (have not yet submitted comments to committee)

Note: The IWMP process was originally designed to facilitate interaction among government agencies; this particular process is unique in that members of the general public were invited to participate on the committee.

Different Perspectives on Past Practices and Problems in Planning Area:

- Forest Company: Area is generally stable; some steep slopes subject to frost heaving and erosion processes; watershed appears to have "natural filtering" capacity (smaller streams disappear mid-reach and reappear further down
- Forest Service: Require terrain classification and slope stability analysis
- Archaeology Branch: Recent past road construction has destroyed some potentially significant historic sites
- Ministry of Health: Planning process should evaluate past land use impacts
- Regional District: Lacks confidence in allowing development based on experience in GVRD and GVWD
- Ministry of Environment, Lands and Parks: Address past land use impacts and use information to guide development process; rehabilitate one of the creeks which has a sediment problem in winter run-off period
- Department of Fisheries and Oceans: There are impassable barriers for fish
- Trapper: Drainage structures have been inadequate throughout the area

Summary of Water Quality, Quantity and Allocation Concerns	
Ministry of Forests	Objective is to protect or enhance the quality/quantity of water on Crown land
Ministry of Health	Objective is to achieve highest level of raw water quality practical; advocate use of monitoring program to evaluate risk but must set parameters and frequency
Town and Regional District	Objective is to maintain and improve water quality and quantity in perpetuity
Ministry of Environment, Lands and Parks	Plan should limit short term impacts to acceptable levels while ensuring no long term impact; collect and assess quality/quantity data; determine present and future water allocations
Fish and Wildlife	Maintain water quality/quantity and habitat to support all fish life stages and maintain populations; consider water treatment
Department of Fisheries and Oceans	Protect water quality/quantity for anadromous and resident fish
Citizen Participants	Protect water quality.
Ministry of Energy, Mines and Petroleum Resources	Objective is to ensure that high quality domestic water supplies are maintained

Summary of Short-term Resource Extraction Plans	
Forest Companies	No plans for timber extraction for at least five years
Ministry of Forests	The area currently contributes to Small Business Forest Enterprise Program (SBFEP) allowable annual cut; some priority to remove stands infected with root rot through IWMP process
Archaeology Branch	No designated historic sites, but will provide input into development plans for avoiding significant sites
Ministry of Health	Impact assessment required before any resource extraction
Town	Resolved by council that there should be no activity in one watershed and restricted activity in the other
Regional District	Opposed to any development that may degrade water supply
Ministry of Environment, Lands and Parks	Proceed according to IWMP Terms of Reference and guidelines
Fish and Wildlife	Licensed trapline in area; support process
Department of Fisheries	Must maintain no net loss to fishery; support process
Ministry of Energy, Mines, and Petroleum Resources	Two mineral claims in area which are not currently active but activity is required to maintain status of claims
Citizens	All agree on proceeding with process; one advocates no logging or mining, but possibly recreation

Summary of Long-term Resource Extraction Plans	
Forest Companies	Both plan forest management activities according to Tree Farm License and/or IWMP
Forest Service	Forest management will take place according to integrated resource principles and this IWMP
Town	Considering a pipeline from one of the systems
Fish and Wildlife/ Department of Fisheries and Oceans	Opposed to pipeline that would decrease flow from creek
Ministry of Energy, Mines and Petroleum Resources	Moderate potential for metallic, coal or industrial material extraction

Summary of Opinions on Forest Practices/Standards and Guidelines:

Range of opinions:

- existing standards, regulations and/or guidelines are enough
- existing guidelines require review
- some adjustment of guidelines in riparian zone and to protect or benefit fish and wildlife habitat are required
- even more stringent regulations on logging are required

Summary of Opinions on Access to Planning Area:

Range of opinions:

- maintain restricted access
- controlled access to parts of the watershed
- controlled access to all of watershed
- unrestricted access to traplines

Summary of Opinions on Recreational Use of Planning Area:

- Public recreational opportunities and demands are not being satisfied due to restricted access
- Possibility for archaeological field school for heritage interpretation in an eco-museum type setting
- Establish an education program for watershed users
- No recreational use of one lake should be allowed, and restricted access to the others (e.g., hiking, fishing an non-motorized boats only)
- Should consider water treatment options which would allow recreational use of the watershed. Closure to wildlife viewing, trapping, hunting, or angling is unacceptable.
- Minimal recreational salmon sports fishing possibilities. Maintain aesthetic values for water-based recreation.
- Significant usage of cabins in the area, especially by Junior Forest Wardens
- Recreational hiking may be an acceptable activity

Summary of Information needs (Requested by):

- Terrain classification and slope stability analysis (MoF)
- Digitizing and merging of all forest resource information (MoF)
- Archaeology study (AB)
- Catchment areas defined (Town)
- Legal survey of catchment areas (Town)

- Hydrology report (MoELP)
- Water quality assessment (MoELP)
- Existing licensed demand quantity (MoELP)
- Comments or concerns by water users, including all downstream licensees, fisheries, etc. (MoELP)
- Proposed water use and land use activities within the watershed (MoELP)
- Review of existing related guidelines and standards (MoELP)
- Increased frequency of turbidity readings (MoELP)
- Identification of sediment sources, possible rehabilitation measures and cost (MoELP)
- Potential presence of endangered species (F&W)
- Inventory of game and non-game species (F&W)
- Biophysical survey to assess coho production potential, including feasibility for colonization (DFO)
- Inventory of fisheries habitat parameters, population dynamics and carrying capacity on both creek systems
- Identification, location, and possible use of cabins in the planning area (Citizen)

An Important Barrier to Watershed Analysis:

- lack of congruency among data sets from different jurisdictions and different land owners.

Appendix D
The Status of Integrated Watershed Management Plans (IWMP's)[2]

REGION	REPORT SIGNED	UNDERWAY
Vancouver Island	none	Holland Creek
Lower Mainland	Norrish Creek Pemberton Creek	Chapman Creek Stawamus River/ Mashiter Creek
Southern Interior		
Penticton	Penticton Creek	Hydraulic Creek Naramata Creek
Kamloops	Clinton Creek Russell/Hascheak Creek	none
Kootenay	Dolan Creek Springer Creek Hasty/Aylwin Creek	Arrow Creek Duck Creek Mark Creek Nelson w/s Blueberry Creek Sitkum Creek
Northern Interior		
Prince George	none	Morfee Lakes
Fort St. John	Kiskatinaw River	none
Williams Lake	none	none
Skeena	none	Two Mile Creek

[2]As of April 10, 1992.

Appendix E
A Summary of Community Water Supply Monitoring - FY 92/93[3]

REGION	WATERSHED	STATUS
Vancouver Island	Quatse Lake (Coal Harbour)	Monitoring Underway
	Holland Creek/Stocking Lake (Ladysmith/Saltair)	Monitoring underway
Lower Mainland	Chapman/Gray Creeks	Monitoring Underway
Southern Interior	Naramata/Robinson Creeks	Proposal coming from Region (assessment in 93/94)
	Mission Creek Kelowna Creek Duteau Creek Vernon Creek Coldstream Creek Hydraulic Creek Peachland Creek	Objectives set; monitoring underway
	Penticton Creek Summerland Creek Trout Creek	Assessment in 93/94
Kootenay Region	Five Mile Creek (Nelson)	Data assessment indicates further monitoring needed
	Selous Creek (Nelson) Anderson/Fell Creeks (Nelson) Lasca Creek	Monitoring/assessment desired exceeds resources
Northern Interior	Kiskatinaw River (Dawson Creek)	Monitoring underway
	Bridge Creek (100 Mile House)	Data assessment planned for 92/93 before further monitoring

[3]As of April 10, 1992.

Watershed Monitoring Requested by Regions[4]

Vancouver Island Region:

- Nile Creek (Qualicum Bay-Horne Lake)
- Cusheon Lake (Saltspring Island)
- Langley Lake (Union Bay)
- Greater Victoria Water District (District monitors itself)
- Banon Creek (Chemainus)
- Shawnigan Lake/Creek (Shawnigan Lake/Mill Bay)
- Graham Lake (Denman Island)
- Magic Lake/Pender Lake (Pender Island)

Lower Mainland Region:

- Norrish Creek (Dewdney-Allouette R.D.)
- Land Creek (Brew Bay/ Powell R. R.D.)
- Stawamus River (Squamish)

Southern Interior Region:

- East Canoe Creek (Salmon Arm Area)
- Russell Creek (Clearwater Area)
- Hascheak Creek (Clearwater Area)
- Gill Creek (Clearwater Area)
- Brash Creek (Salmon Arm Area)
- Hudson Creek (Salmon Arm Area)
- Silver Creek (Salmon Arm Area)
- Boss Creek (Salmon Arm Area)
- Owlhead Creek (Salmon Arm Area)
- Avola (Clearwater Area)
- Blue River (Clearwater Area)
- White River (Clearwater Area)
- Foghorn Creek (Birch Island)
- Barriere River (Barriere)
- Brookmere (Merritt Area)
- Shovelnose (Merritt Area)
- Thyme (Merritt Area)

[4]As of April 10, 1992.

Appendix F
Sediment Budget Studies in the Prince Rupert Forest Region

SEDIMENT BUDGET STUDIES IN THE PRINCE RUPERT FOREST REGION

A STATEMENT OF THE PROBLEM AND

SHORT LITERATURE REVIEW [1]

By Pierre Beaudry
Forest Hydrologist
Prince Rupert Forest Region

1.0 INTRODUCTION

1.1 Environmental concern

With recent increases in public environmental awareness, the British Columbia forest industry has been the focus of heavy criticism. Among the perceived problems are increased erosion rates, loss of productive land base and excessive stream sedimentation resulting from past and present harvesting practices.

The negative effects of excessive sedimentation on fish have been well documented. They include: suffocation of the eggs when the sediment is deposited (Philips et. al. 1975, Hartman and Scrivner 1990), filling of the pools and interstitial spaces in the bed and thereby reducing available habitat (Saunders and Smith 1965, Bjornn et al 1977), and direct mortality of salmonoid fish when suspended sediment levels are extremely high (Noggle 1978). However, the negative effects of increased sedimentation are not confined to fish, they can also include: deterioration of water quality for domestic and industrial water supplies, reduction in the quality of the wilderness recreational experience and a reduction in fishing opportunities which in turn has a significant impact on the guide-outfitter industry. In west central British Columbia all of these potential sedimentation impacts are real concerns and have been publicly voiced by numerous interest groups (Beaudry and Schwab 1989, 1990).

1.2 Operational Problem

The impacts of forest harvesting operations on erosion, sediment delivery and stream sedimentation are extremely inconstant throughout the province and depend on numerous environmental and human variables. The obvious ones include: geomorphic characteristics of the watershed, weather patterns, soil types, harvesting methods, road construction and maintenance practices and operator performance. Numerous scientific papers, handbooks and guidelines are available which focuses on the problems of erosion and stream sedimentation and they provide excellent recommendations to reduce these problems (Chatwin et. al. 1991, Carr 1980, 1992).

However, it remains difficult to predict relatively accurately how much erosion and sedimentation will occur over an entire watershed for a specific 5 year logging plan at the planning phase of the operation.

Presented to the Modelling Forestry - Drinking Water Quality Interactions Workshop March 2-3, 1993, Cowichan Lake Research Station. Hosted jointly by Ministry of Environment, Lands and Parks and the Ministry of Forests. This paper is an excerpt from a research proposal by Pierre Beaudry: "A GIS based procedure for estimating basin sediment delivery".

The following example of an operational situation typifies the problem well:

> The Timber Officer of a local district office wants to open up a new watershed for forest harvesting. Following the public involvement and consultation process he realizes that there is a real concern among the public that logging in that particular watershed will cause a significant deterioration in the quality of the water. This watershed serves as a domestic water supply for the local town and also has a high value fisheries resource. It quickly becomes obvious to the Timber Officer that the concerns are real and significant, and that a detailed environmental impact assessment is justified. An official request, which is usually very brief and not very explicit, is then made to the watershed specialist. It may read something like this: "Could you please do a watershed assessment and indicate all geomorphological and hydrological constraints to logging in this watershed. Thank You!". A proposed logging plan may or may not accompany the request.

What tools and information are available to the watershed specialist to undertake such a study? What procedure or model should be used? Although it is not usually explicitly stated in the operational request, **increased stream sedimentation** is most often the main concern. Thus, a sediment delivery or sediment yield model is needed for objectively assessing the potential effects of forest harvesting on basin sediment yield. This, in essence, is the problem.

To improve the efficiency and objectivity of watershed planning for sediment management purposes, watershed specialists need two fundamental tools:

1) A conceptual basin sediment budget (Reid 1982b) which describes local processes of sediment production, sediment delivery, sediment transport and sediment output.

2) A fairly rigorous methodology or model that will provide a quantitative approximation of the effects of various proposed forest harvesting scenarios on the basin sediment budget.

Such a model, based on the knowledge of local processes and current forest harvesting practices, should go a long way towards a better understanding of the effects of forestry activities on the sediment regime of a particular drainage basin.

2.0 GOAL AND OBJECTIVES

Goal and objectives of sediment budget research in the Prince Rupert Forest Region:

> To develop a quantitative, physically sound, operationally oriented model to be used for comparative analysis of the effects of various forest management scenarios on the sediment budget for a given watershed.

Specific objectives of the sediment budget research project:

1) to modify and adapt a sediment yield procedure such as WRENSS (USDA 1980) for use with a geographic information system (GIS) in an effort to provide an efficient, geographically based, computer assisted Land Information System (LIS) for assessing seasonal sediment delivery in a managed watershed. The LIS should be adaptable as local knowledge increases relative to watershed sediment budgets in the Prince Rupert Forest Region.

2) to validate the LIS on several watersheds within the Prince Rupert Forest Region representing a good cross section of terrain types within the north central transitional zone.

3.0 LITERATURE REVIEW

3.1 Early Studies

Concerns about the impacts of forest harvesting on the water resource are not new in North America, as they have been reported in the literature as far back as the early 1900's (Marsh 1907, The American Tree Association 1921, Zon 1927). Extensive research on this topic began as early as 1908 in North America (Bates and Henry 1928) and today there are well established experimental watersheds to study these effects in most parts of the world, many of them located in Canada (Dickison 1981, Hetherington 1982, Plamondon 1980, Alexander et al. 1977, Calder 1990, Nakano 1971, Pereira 1964, Pearce et al. 1980). As a result of theses studies the effects of forest harvesting on streamflow regime (peak flows, low flows and floods) are now relatively well understood and have been well summarised in Bosch and Hewlitt (1982).

However, the long term effects of forest management practices on the basin sediment budget are still poorly understood and are presently the focus of very active research (Dietrich et al. 1982, Swanson and Fredrickson 1982, Lehre 1981, Reid et al. 1981, Jordan and Slaymaker 1991, Sutherland and Bryan 1991, Roberts and Church 1986, Stott et al. 1988, Megahan et al. 1986, Hrissanthou 1990, Duijsings 1986, Dordas et al. 1988). A drainage basin sediment budget identifies and quantifies the rates of production, transport and discharge of sediment from the watershed (Dietrich et al. 1981). Swanson et al. (1981) describes this methodology as: "providing a useful approach to holistic analysis of drainage-basin functions". Such watershed scale information is necessary for evaluating the relative importance of forest harvesting related sediment sources in the overall sediment budget, and how these sources can be minimized.

A method for constructing a drainage basin sediment budget is proposed by Deitrich et al. (1982). In their paper they state that with a small, but essential amount of field work, an approximate sediment budget can be constructed. The field work must focus on collecting information relative to the major transport and delivery processes that are dominant for a region. With this information on hand, one should be able to create a local conceptual sediment budget model and apply the model to areas of similar hydrologic, geologic and geomorphic characteristics.

Sutherland and Bryan (1991) provide an excellent synopsis of the results of the major sediment budget studies since the first field-based sediment budget study by Leopold et al. (1966). Most of these studies stress that there is no steady-state relationship between erosion and sediment yield, i.e. erosion does not

equal sedimentation (Megahan 1981). They clearly demonstrated that temporary storage of sediment is not negligible for small forested watersheds and thus that the assumption of $\Delta S = 0$ was inappropriate.

Most sediment budget studies have concentrated on describing the natural erosion and sediment delivery processes within a watershed. However, a few studies do exist that describe forest harvesting impacts using a full or partial sediment budget approach (Megahan 1981, 1982, Roberts and Church 1986, Reid et al 1981 and Moore and Newson 1986, Fredriksen 1970, Janda 1978, Jackson et al. 1986, Johnson 1988).

3.2 Construction of a conceptual sediment budget

The construction of a flow chart that qualitatively describes the relationships that exists between various geomorphological processes is considered a valid approach towards a theoretical description of a sediment budget (Reid 1982b). However, this process is not an easy one. During a conference on the subject of sediment budgets (Swanson et al. 1982) experts in this field did not succeed in defining a standard flow chart for describing a basin sediment budget (Reid 1982b). Essentially, they could not agree on one standard format that would accommodate the variability in the importance of various processes that occur in various geomorphic regions.

Although there is no general agreement on a standard format, there is some agreement on the general contents that should be included in a conceptual flow chart sediment budget for mountainous terrain (Dietrich and Dunne 1978):

- the nature and relative importance of all significant types of sediment sources within the watershed.

- the types and relative importance of various sediment movement initiation processes and sediment transfer processes.

- the relative importance of the various sediment storage sites and where they are located in the overall sediment routing process.

- routes of remobilisation of the sediment (possibly towards a different process group)

- a description of the rate and timing of sediment output from the system

- a description of the linkages that exist between processes of sediment production, transfer, modification and storage.

An example of such a flow chart for an undisturbed watershed is provided in Figure 1. Harvesting impacts can alter the relative importance of each of the sediment sources, can create new sources (i.e. roads, landings, skidtrails) and can change or create sediment delivery pathways. The importance of these changes is also influenced by the time of the year in which the activities occur (i.e. initiation of movement). This chart is only indicative of some of the processes that dominate watersheds in the north central transition zone. As field work progresses such a flow chart will be refined. In its present form, this flow chart serves both as an example and as a foundation to build upon as field data become available and knowledge of the important processes improves.

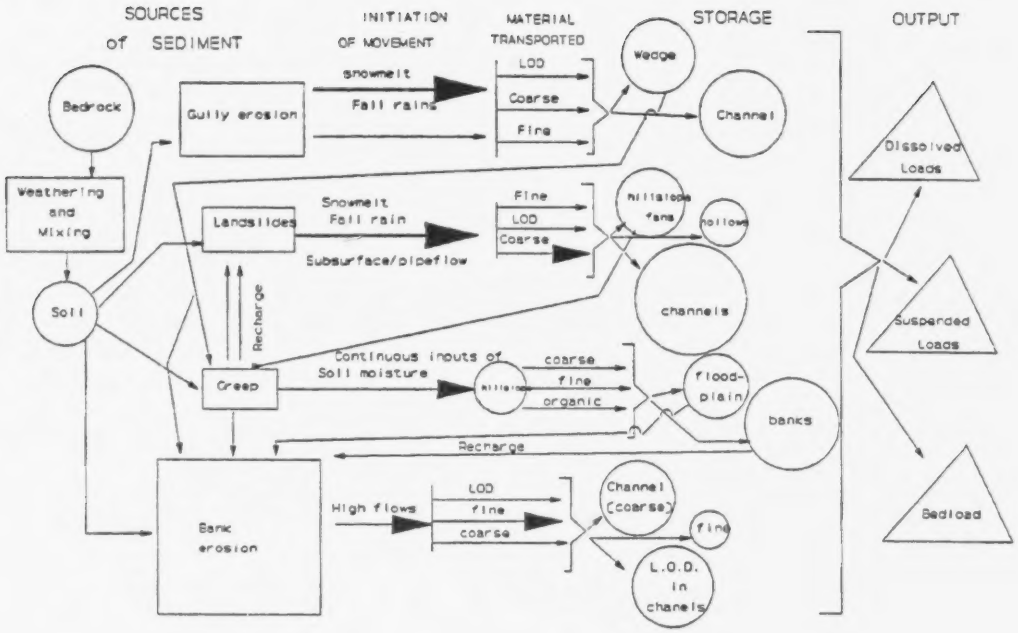

Figure 1: Conceptual sediment budget for a hypothetical watershed within the north western transition zone.

3.3 Approaches to the evaluation of sediment production and delivery

As discussed above, a detailed sediment budget is a useful tool for planning forestry activities. However, its construction for a large watershed can quickly become an enormous and very costly venture (Dietrich et al. 1982, D. Hogan, Pers. com. 1991). Although detailed field measurements are absolutely necessary for understanding the fundamental processes that govern a sediment budget, they are usually not necessary for operational assessments. What is needed is an objective, quantitative model or procedure that produces an approximate basin sediment budget using data that is relatively easily obtained. Thus, the challenge is to find an existing model, or develop a new model, that will adequately quantify the production and transport mechanisms of the various sediment sources within the watershed, yet at the same time be simple enough that it can actually be used for operational planning in forestry. The model must also be adaptable to new research information about the processes that govern the sediment budget.

A plethora of sediment models have been reported in the literature. These models range from simple empirical methods for estimating annual sediment yield at the watershed outlet (Nolan and Janda 1981, Rice 1977, Walling and Webb 1982, Wischmeier and Smith 1960, Burns 1978, Soil Conservation Service 1977, Williams and Brendt 1976, Wilson et al. 1986) to very complex, process based, deterministic models that attempt to mathematically describe every process involved in sediment delivery and sediment

routing (Simons et al. 1982, Grayson et al. 1988, Moore and Burch 186, Beasley 1986, Moore et al. 1988).

The problem with the simple empirical models is that they do not describe the processes and thus are difficult to use outside of the range of calibration (Foster 1988) especially when point source activities, such as road building, landings and logging occur on a watershed. Another problem is that such models often only predict sediment yield at the basin outlet and assume that there is a steady state relationship between erosion and sediment yield. These models also do not provide any information about the relative importance of various sediment producing sources within a watershed and thus cannot be used to focus on particular problematic areas within a watershed. At the other end of the spectrum are the complex mathematical models which require vast amounts of descriptive data to perform optimally. Such models have been used successfully in agriculture where conditions are relatively uniform and descriptive field data is relatively easy to collect (Hodge et al. 1988, Gilliland and Baxter-Potter 1987). However, for a large, very heterogeneous unroaded watershed only the very simplistic descriptive data is obtainable. Attempting to use complex deterministic models on a undisturbed watershed, for predictive purposes, would be futile because most of the data necessary to run the model would be unavailable.

The literature provides numerous studies that describes the effects of forest management practices on sediment production (Swanson et al. 1987, Rice and Datzman 1981, Miller et al. 1988, Megahan 1987, Heede and King 1990, Anderson and Potts 1987). The most important forest harvesting related source of sediment has been clearly demonstrated to be associated with the building and improper maintenance of logging roads and skid trails (Rothwell 1978, Packer 1967, McCashion and Rice 1983, Commandeur 1990). Consequently, this subject has attracted the most research attention and has been very well documented (Reid et al. 1981, Megahan et al. 1986, Reid and Dunne 1984, Bilby 1985, Bilby et al. 1989, Rice and McCashion 1985, Swanson et al. 1987). However, these studies, which focused on erosion and sediment production provided very little information about the process of sediment delivery to the stream. Also, they were generally site specific and did not discuss the relative importance of a particular sediment producing mechanism in relation to all of the other sediment sources in the watershed. Only a few authors have attempted to provide a predictive modelling tool for operational use in forestry that deals both with sediment production and sediment delivery (Burns and Hewlett 1983, USDA 1980, Packer 1967).

In British Columbia a descriptive procedure has been developed to highlight or "red flag" a watershed that may be overly sensitive to a proposed development plan (Hogan and Wilford 1989). This descriptive method provides a framework on which to base discussions between resource agencies about the potential overall effects of proposed harvesting within a watershed. The sediment transfer hazard classification system (Hogan and Wilford 1989) provides a basin level approach to a qualitative assessment of sediment delivery and sediment throughput. It maintains a sediment budget philosophy; analyzing each sediment source and its potential delivery route individually. The procedure completes the process by routing the sediment down the stream and out of the watershed. However, each step describes only a conceptual process and no attempt has been made to measure and quantify the various processes involved in the procedure. This provides a difficulty for comparing the relative importance of various sediment sources and the site specific and cumulative impacts that a proposed harvesting plan may have. The author recognizes that quantitative assessments would improve the procedure and hopes to continue the development of the method in a more quantitative fashion (D. Hogan, pers. com. 1991).

On the quantitative side, a few sediment budget studies have been done in B.C. (Jordan and Slaymaker 1991, Roberts and Church 1986) or are presently underway (Hogan and Chatwin 1990). These studies

have provided excellent fundamental information about basin scale sediment routing processes. However, they do not provide the watershed manager with a clear methodology for extrapolating this information to unmonitored basins.

Thus, what is needed for operational watershed management planning in B.C. is a quantitative methodology or procedure that builds on the information already available, takes advantage of modern technologies and is adaptable to ongoing research results. The data required for this methodology or model must be obtainable over a relatively short time, i.e. 6-10 months, or management plans will go ahead without hydrological or geomorphological input.

4.0 BIBLIOGRAPGY

Alexander, P.R. and Watkins, R.K., 1977. The Frazer experimental forest, Colorado. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. RM-40, 32pp.

Band L.E., 1986. Topographic partition of watersheds with digital elevation models. Water Resour. Res., 22(1):15-24.

Band L.E., 1989. A terrain-based information system. Hydrol. Processes 3:151-162.

Bates C.G. and A.J. Henry, 1928. Forest and streamflow experiments at Wagon Wheel Gap, Colorado. USDA Weather Bureau Monthly Weather Review. Supl. No. 30, Washington, D.C. USA

Beasley D.B., 1986. Distributed parameter hydrologic and water quality modeling. In: Agricultural non-point source pollution: Model selection and application. Elsevier Publ. Co. New York, NY pp 173-190.

Beaudry P.G., and J.W. Schwab, 1989. Telkwa Watershed. A Forest Hydrology Analysis. B.C. Forest Service, Internal Consulting Report, Smithers. 22 p.

Beaudry P.G., and J.W. Schwab, 1990. Wathl Creek Watershed. A Forest Hydrology Analysis. B.C. Forest Service, Internal Consulting Report, Smithers. 24 p.

Beaudry, P.G., J.W. Schwab and D. Septer, 1991. Suspended sediment - Telkwa River Watershed. Operational report. B.C. Forest Service, Forest Sciences Section, Smithers. B.C. 23 pg.

Bilby, R.E., 1985. Contributions of road surface sediment to a western Washington stream. Forest Science. 31(4):827-838.

Bilby, R.E., K. Sullivan and S.H. Duncan, 1989. The generation and fate of road-surface sediment in forested watersheds in southwestern Washington. Forest Science. 35(2):453-468.

Bjornn, T.C. et al., 1977. Transport of granitic sediment in streams and its effect on insects and fish. For., Wildl., and Range Exp. Stn. Bull. No 17. Univ. of Idaho, Moscow.

Bordas M.P., A.E Lanna and F.R. Semmelmann, 1988. Evaluation des risques d'erosion et de sedimentation au bresil a partir de bilans sedimentologiques rudimentaires. In: Sediment budgets. Proceedings of the Porto Alegre symposium, December 1988. IAHS Publi. no. 174, 1988.

Bosch J.M. and J.D. Hewlett, 1982. A review of catchment experiments to determine the efect of vegetation changes on water yield and evapotranspiration. J.Hydrol., 55:2-23.

Burns R.G, 1978. An improved sediment delivery model for Piedmont forests. Ph.D. dissertation. University of Georgia. Athens Georgia. 72 pp.

Burns R.G. and J.D. Hewlett, 1983. A decision model to predict sediment yield from forest practices. Water Resour. Bull., 19(1):9-14.

Calder I.R., 1990. Evaporation in the uplands. John Wiley and Sons. 148pp.

Carr, W.W., and I. Wright 1992. A soil erosion and sediment control planning system for managed forest land: A case study at Shomar Creek, Queen Charlotte Islands. B.C. Land management Report NUMBER 60, B.C.Ministry of Forests.

Carr, W.W. and T.M. Ballard, 1980. Hydroseeding forest roadsides in British Columbia for erosion control. J. Soil Water Conserv., 35(1): 33-35.

Carrara A., M Cardinalli, R. Detti, F. Guzzetti, V. Pasqui, and P. Reichenbach, 1991. GIS techniques and statistical models in evaluating landslide hazard. Earth Surf. Processes and Landforms. 16:427-445.

Chatwin S.C., D.E. Howes, J.W. Schwab and D.N. Swanston, 1991. A guide for management of landslide-prone terrain in the Pacific Northwest. B.C. Ministry of Forest, Victoria. Land Management Handbook No 18, 212 pages.

Commandeur P.R., 1990 Erosion and sedimentation within forested land in British Columbia - A problem analysis. Forestry Canada, Pacfic Forestry Centre - Research Report (In Press)

De Roo A.P.J., L. Hazelhoff and P.A. Burrough, 1989. Soil erosion modelling using 'ANSWERS' and Geographical Information Systems. Earth Surf. Processes and Landforms., 14:517-532.

Dickison, R.B.B., D.A. Daugharty, and D.K. Randall, 1981. Some preliminary results of the hydrologic effects of clearcutting a small watershed in central New Brunswick,. In: Proc. 5th Can. Hydrotech. Conf., Fredericton, N.B. Canadian Society of Civil Engineers. p.59-75.

Dietrich W.E. and T. Dunne, 1978. Sediment budget for a small catchment in mountainous terrain. Z. Geomorph. N.Z. Suppl. Bd. 29:191-206

Dietrich, W.E., T. Dunne, N.F. Humphrey, and L.M. Reid, 1982. Construction of sediment budgets for drainage basins. In: Sediment Budgets and Routing in Forested Drainage Basins. pp.5-23. F.S. Swanson et. as. (eds). USDA For. Ser. Gen. Tech. Rep. PNW-141.

Dissmeyer, G.E., 1982. How to use the fabric dam to compare erosion from forestry practices. USDA For. Serv. Forestry report SA-FR 13, 10p.

Doornkamp J.C. and C. A. M King, 1971. Numerical analysis in geomorphology - an introduction. Edward Arnold Press, London. 356p

Duijsings J.J.H.M., 1986. The sediment supply by streambank erosion in a forested catchment. Z. Geomorph. N.Z. Suppl. Bd. 60: 233-244.

Foster G. R., 1988. Development and use of models for management of runoff and erosion processes. In: Modeling agricultural, forest, and rangeland hydrology. pp 447-461. Proceeding of the 1988 International Sympsium. Chicago Illinois, Dec. 12-13, 1988. ASAE

Franklin S.E., 1987. Geomorphometric processing of digital elevation models. Computers and Geosciences 13(6):603-609

Fredriksen R.L., 1970. Erosion and sedimentation following road construction and timber harvest on unstable soils in three small western Oregon waterseds. USDA For. Serv. Res. Pap. PNW 104, 15p. Pac. Northwest For. and Range Exp. Stn. Portland Oreg.

Gardner T.W., K.C. Sasowsky and R.L. Day, 1990. Automated extraction of geomorphic properties from digital elevation data. Z. Geomorph. N.Z. Suppl. Bd. 80:57-68.

Gersmell, P.J., 1987. Use of a cellular geographic informatio system in assessing soil erosion and sediment deposition in two medium sized watersheds. In: Proceedings:URISA - 25th Annual Conference, Vol 1, Land Records/ Natural Resources pp. 140-151.

Gilliland M.W. and W. Baxter-Potter, 1987. A geographic information system to predict non-point source pollution potential. Water Resour. Bull. 23(2)281-291.

Grayson, R.B., I.D. Moore, E.M. O'louglin and A.K. Turner, 1988. The development of a hydrologic model for erosion prediction. Conf. on Agr. Eng., 25-29 September, Sydney, Australia. National Conf. Publ No. 88/xx, Inst Engrs. Aust. (in press). Water Resour. Bull.

Hartman, G.F. and J.C. Scrivner, 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Can. Bull. Fish. Aquat. Sci., 223, 148p.

Heede, B.H. and R.M. King, 1990. State-of-the-art timber harvest in an Arizona mixed conifer forest has minimal effect on overland flow and erosion. J. Hydrol. Sciences. 35(6):623-635.??

Hetherington, E.D., 1982. Effects of forest harvesting on the hydrologic regime of Carnation Creek experimental watershed: a preliminary assessment. In: Proc. Can Hydrol. Symp. '82. National Research Council of Canada, Ottawa, Ont. p 247-267.

Hodge W., M. Larson and W. Goran, 1988. Linking the ARMSED watershed process model with the GRASS geographic information system. In: Modeling agricultural, forest, and rangeland hydrology. pp 447-461. Proceeding of the 1988 International Sympsium. Chicago Illinois, Dec. 12-13, 1988. ASAE

Hogan D.L. and D.J. Wilford, 1989. A sediment transfer hazard classification system: Linking erosion to fish habitat. In: Watershed '89. A conference on the stewardship of soil, air and water resources. Juneau, Alaska, 21-23 March 1989. USDA For. Ser. R10-MB-77 p 143-155.

Hogan D.L. and S. Chatwin, 1990. Tsitika River sedimentation monitoring program. Working plan prepared for the Tsitika River Follow-up Committee. Unpublished report, B.C. Ministry of Forests, Vancouver Region, Forest Sciences Section, 19 p.

Hrissanthou V., 1990. Application of a sediment routing model to a middle european watershed. Water Resour. Bull. 26(5):801-810.

Jackson, W.L., K. Gebhardt and B.P. Van Haveren, 1986. Use of the modified universal soil loss equation for average annual sediment yield estimates on small rangeland drainage basins. In: Drainage Basin Sediment Delivery, R.F. Hadley (ed). pp. 413-422, I.A.H.S. Publ. No. 159. Albuquerque, New Mexico, U.S.A.

U.S.A.

Miller E.L., R.S. Beasley, and E.R. Lawson, 1988. Forest harvest and site preparation effects on erosion and sedimentation in the Ouachita mountians. J. Environ. Qual. 17(2):219-225.

Moore I.D., J.C. Panuska, R.B. Grayson and K.P. Srivastava, 1988. Application of digital topgraphic modeling in hydrology. In: Modeling agricultural, forest, and rangeland hydrology. pp 447-461. Proceeding of the 1988 International Sympsium. Chicago Illinois, Dec. 12-13, 1988. ASAE

Moore, I.D. and G.J. Burch, 1986. Modeling erosion and deposition: Topographic effects. TRANS. of the ASAE., 29:1624-1630.

Moore, I.D., E.M. O'loughlin and G.J. Bunch, 1988. A contour-based topographic model for hydrological and ecological applications. Earth Surf. Processes and Landforms., 13(4): in press.

Moore, R.J. and M.D. Newson, 1986. Production, storage and output of coarse upland sediment: natural and artificial influences as revealed by research catchment studies. Jour. of the Geological Society, London. 143: 921-926.

Morris, D.G. and R.C. Heerdegen, 1988. Automatically derived catchment boundaries and channel networks and their hydrological applications. Geomorphology 1:131-141.

Nakano, H., 1971. Effect on streamflow of forest cutting and change in regrowth on cutover area. Repr., Bull. U.S. Gov. For. Exp. Stn., No. 240, 249 pp.

Neter, J. and P. Wasserman, 1974. Applied linear statistical models. Richard D. Irwin, Inc. Homewood, Illinois, 842 p.

Noggle, C.C., 1978. Behavioral, physiological and lethal effects of suspended sediment on juvenile salmonids. M.S. Thesis, University of Wahington, Seattle 87p.

Nolan M.K. and J. Janda, 1981. Use of short-term water and suspended-sediment discharge observations to assess impacts of logging on stream-sediment discharge in the Redwood Creek basin, northwestern Californis, U.S.A.. In: Erosion and sediment transport in the Pacific Rim steeplands. Proceedings of the Christchurch Symposium, January 1981. IAHS Publ. no 132.

Oslin A.J., R.A. Westsmith and D.S. Morgan, 1988. STREAMS: A basin and soil erosion model using CADD, remote sensing and GIS to facilitate watershed management. In: Modeling agricultural, forest, and rangeland hydrology. pp 470-477. Proceeding of the 1988 International Sympsium. Chicago Illinois, Dec. 12-13, 1988. ASAE

Packer, P.E., 1967. Criteria for designing and locating logging roads to control sediment. Forest Science. 13(1):2-18.

Pearce, A.J., L.K. Rowe, and C.L. O'Oloughlin, 1980. Effects of clearfellinandslash urning on water yeld and storm hydrographs in evergreen mixed forests, western New Zealand. In: Proc. on Influence of Man on the Hydrlogical Regime with Special Reference to Representative and Experimental Basins, Helsinki, June 1980 IAHS Publ No 130, pp 119-127.

Janda R.L., 1978. Summary of watershed conditions in the vicinity of Redwood National Park, Calif. . U.S. Geol. Surv. Open-File Rep. 78-25, 82p.

Jensen S.K. and J.O. Dominique, 1988. Extracting topographic sructure from digital elevation data for geographic information system analysis. Photogramm. Engng. Remote Sens., 54(11):1593-1600.

Johnson R.C., 1988. Changes in the sediment output of two upland drainage basins during forestry land use changes. In: Sediment budgets. Proceedings of the Porto Alegre symposium, December 1988. IAHS Publi. no. 174, 1988.

Jordan, P. and O. Slaymaker, 1991. Holocene sediment production in Lillooet river basin, British Columbia: a sediment budget approach. Geographie physique et Quaternaire 45(1):45-57.

Lehre A.K., 1981. Sediment budget of a small California Coast Range drainage basin near San Francisco. In: Erosion and sediment transport in the Pacific Rim steeplands. Proceedings of the Christchurch Symposium, January 1981. IAHS Publ. no 132.

Leopold, L.B., W.W. Emmett, and R.M. Myrick, 1966. Channel and hillslope processes in a semiarid, New Mexico. United States Geological Survey Professional Paper, 352-G, 193-253.

Logan T.J., D.R. Urban, J.R. Adams and S.M. Yaksich, 1982 Erosion control potential with conservation tillage in the Lake Erie Basin: Estimates using the universal soil loss equation and the Land Resource Information System (LRIS) J. Soil Water Conserv., 37(1):50-55

Marsh G.P., 1907. The earth as modified by human action. New York: Scribners.

McCashion J.D. and R. M. Rice, 1983. Erosion on logging roads in northwestern California: how much is avoidable?. J. Forestry. 1:23-26

McCool D.K., M.G. Dossett and S.J. Yecha, 1981. A portible rill meter for field measurement of soil loss. In: Erosion and sediment transport measurement. Proceedings of the Florence Symposium, June 1981. IAHS Publ. no. 133.

Megahan W.F., 1987. Increased sedimentation following helicopter logging and prescribed burning on granitic soil. Erosion and sedimentation in the Pacific Rim. Proceedings of the Corvallis Symposium, August 1987. IAHS Publ. no. 165.

Megahan W.F., 1982. Channel sediment storage behind obstructions in forested drainage basins draining the granitic bedrock of the Idaho batholith. In: Sediment Budgets and Routing in Forested Drainage Basins. pp.5-23. F.S. Swanson et. as. (eds). USDA For. Ser. Gen. Tech. Rep. PNW-141.

Megahan W.F., 1981. Effects of silvicultural practices on erosion and sedimentation in the interior West - A case for sediment budgeting. In: Interior Est Watershed Management. Proceedings of a symposium, D.M. Baumgartner (ed), Washington State U., Coop. Ext., April 8-10, 1980. p.169-182.

Megahan, W.F., K.A. Seyedbagheri, T.L. Mosko and G.L. Ketcheson, 1986. Construction phase sediment budget for forest roads on granitic slopes in Idaho. In: Drainage Basin Sediment Delivery, R.F. Hadley (ed). pp. 31-39, I.A.H.S. Publ. No. 159. Albuquerque, New Mexico,

Pereira, H.C., 1964. Research into the effects of land use on streamflow. Trans. Rhod. Sci. Assoc. Proc. 1: 119-124.

Philips, R.W., R.L. Lantz, E.W. Claire, and J.R. Moring, 1975. Some effects of gravel mixtures on emergence of Coho salmon and steelhead trout fry. Trans. Am. Fish. Soc. 104(3):461-466.

Plamondon, A.P., and D.C. Ouellet, 1980. Partial clearcutting and streamflow regime of ruisseau Eaux-Volees experimental basin. In: Proc. Helsinki Symp. IAHS Publ. No. 130. . 129-136.

Ranger, G.E. and F.F. Franklin, 1978. The 3-F erosion bridge - a new tool for measuring soil erosion. California State Dept. Forestry. Range Improvement studies, No. 23.

Reid L.M., T Dunne and C.J. Cederholm, 1981. Application of sediment budget studies to the evaluation of logging road impacts. J. of Hydrology (N.Z.) 20(1):49-62.

Reid, L.M. and T. Dunne, 1984. Sediment production from forest road surfaces. Water Resour. Res. 20(11):1753-1761.

Reid, L.M., 1982a Evaluating and mapping sources and temporary storage areas of sediment. In: Sediment Budgets and Routing in Forested Drainage Basins. pp.138-141. F.S. Swanson et. as. (eds). USDA For. Ser. Gen. Tech. Rep. PNW-141.

Reid, L.M., 1982b The use of flow charts in sediment routing analysis. In: Sediment Budgets and Routing in Forested Drainage Basins. pp.154-165. F.S. Swanson et. as. (eds). USDA For. Ser. Gen. Tech. Rep. PNW-141.

Rice R.M. and J.D. McCashion, 1985. Site conditions related to erosion on logging roads. In: Proceedings of the international symposium on erosion, debris flow and disaster prevention, Tsukaba, Japan.

Rice R.M., 1977. Estimating sedimentation from an erosion-hazard rating. USDA Forest Service Res. Note PSW-323, 4p., Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Rice R.M., and P.A Datzman, 1981. Erosion associated with cable and tractor logging in north-western California. In: Erosion and sediment transport in the Pacific Rim steeplands. Proceedings of the Christchurch Symposium, January 1981. IAHS Publ. no 132.

Roberts, R.G. and M. Church, 1986. The sediment budget in severely disturbed watersheds, Queen Charlotte Ranges, British Columbia. Can. Jour. For. Res. 16:1092-1106.

Ryder J.M. and D.M. Howes, 1984. Terrain information: a user's guide to terrain maps in British Columbia. B.C. Min of Environment, 16 p.

Saunders, J.W. and M.W. Smith, 1965. Changes in a stream population of trout associated with silt. J. Fish. Res. Bd. Can. 22:395-404.

Simons, D.B., R. Li, T.J. Ward, and L.Y. Shiao, 1982. Modeling of water and sediment yields from forested drainage basins. In: Sediment Budgets and Routing in Forested Drainage Basins. pp.24-38. F.S. Swanson et. as. (eds). USDA For. Ser. Gen. Tech. Rep. PNW-141.

Soil Conservation Service, 1977. Procedure for computing sheet and rill erosion on project areas. USDA SCS Technical Release No 51(Rev 2), Geology 15pp.

Stott, T.A. R.I. Ferguson, R.C. Johnson and M.D. Newson, 1986. Sediment budgets in forested and unforested basins in upland Scotland. In: Drainage Basin Sediment Delivery, R.F. Hadley (ed). pp. 57-68, I.A.H.S. Publ. No. 159. Albuquerque, New Mexico, U.S.A.

Sutherland R.A. and R.B. Bryan, 1991. Sediment budgeting: a case study in the Katiorin drainage basin, Kenya. Earth Surf. Processes and Landforms. 16:383-389.

Swanson, F.J. and R.L. Fredriksen, 1982. Sediment routing and budgets:implications for judging impacts of forestry practices. In: Sediment Budgets and Routing in Forested Drainage Basins. pp.129-137. F.S. Swanson et. as. (eds). USDA For. Ser. Gen. Tech. Rep. PNW-141.

Swanson, F.J., L.E. Benda, S.H. Duncan, G.E. Grant, W.F. Megahan, L.M. Reid and 1987. Mass failures and other processes of sediment production in pacific northwest forest landscapes. In: Streamside Management: Forestry and Fishery Interactions. E.O. Salo and T.W. Cundy (eds). pp. 9-38. U. of Washington, Seattle, Wash. Contribution No. 57

The American Tree Association, 1927. Floods, Forests and the Future. Published by the American Tree Association, Washington, D.C. 32 pp.

Thomas D.L. and D.B. Beasley, 1986. A physically-based forest hydrology model I: Develpment and sensitivity of components. Trans. of the ASAE 29(4):962-972.

USDA Forest Service, 1980. WRENSS: An approach to WATER RESOURCES EVALUATION OF NON-POINT SILVICULTURAL SOURCES (A Procedural Handbook). "Special" Report Series, Office of Research and Development, U.S. Environmental Protection Agency. Interagency Agreement No. EPA-IAG-D6-0660., Athens, Georgia.

Wadge G., 1988. The potential of GIS modelling of gravity flows and slope instabilities. Int. J. Geog. Info. Systems 2(2): 143-152.

Wilford D.J., 1987. Watershed Workbook. Forest hydrology sensitivity analysis for Coastal British Columbia watersheds. B.C. Ministry of Forests, Research Branch, B.C. 33p.

Williams, J.R. and H.D. Brendt., 1976. Sediment yield prediction based on waterhsed hydrology. Winter meeting , Amer. Soc. Agric Eng. Chicago, Ill. Dec. 1976. Paper no 76-2535

Wilson B.N., B.J. Barfield and R.C. Warner, 1986. Simple models to evaluate non-point pollution sources and controls. In: Agricultural non-point source pollution: Model selection and application. Elsevier Publ. Co. New York, NY pp 173-190.

Wischmeier, W.H., and D.D. Smith, 1960. A universal soil loss equation to guide conservation farm planning. In: Int. Congr Soil Sci., Trans. 7th (Madison, Wis) 1:418-424

Zon, R., 1927. Forests and water in the light of scientific investigation. Washington, D.C.: U.S. Government Printing Office

Appendix G
Ministry of Health Giardia Program

Purpose:

To assist in the safe purveyance of drinking water in British Columbia by determining priorities for preventative strategies. The five-year goal of the program is to understand waterborne transmission of giardiasis in British Columbia.

Goals:

1. To acquire, organize and maintain a depot of current information pertaining to the development of more sensitive and specific laboratory tests for *Giardia* cyst detection in drinking water.

2. To introduce a state-of-the-art method of laboratory testing of drinking water for the presence of *Giardia* cysts.

3. To test selected drinking water sites in high-risk watersheds with practical hypotheses in mind.

4. To initiate development of improved methods of laboratory testing particularly as it relates to British Columbia drinking water.

5. To continue to study the epidemiology of waterborne transmission in British Columbia using various investigative methods such as the biochemical and immunological characterization of human, environmental and animal-source *Giardia* isolates.

Progress:

Goal 1. Achieved and ongoing.

Goal 2. Achieved.

Goal 3. Achieved. Work ongoing.

Goal 4. Work ongoing.

Goal 5. Work ongoing.

Services Established Under the Program:

1. State-of-the-art cyst detection method for examination of drinking water (service evaluation and quality assurance ongoing)

2. Computer program for entry of data and summary of results

3. Animal model for cysts viability testing

4. Laboratory support for investigation of outbreaks of giardiasis in British Columbia

5. Giardia Advisory Committee: monitoring of ongoing projects and discussion of drinking water quality, risk assessment, etc.

Projects Underway:

1. Cyst detection in drinking water samples collected from throughout British Columbia and most recently in one selected water system

2. Ongoing study of factors that decrease cyst concentration (reservoir action and chlorination) and cyst viability in drinking water supplies

3. Biotyping of Giardia isolates retrieved from British Columbia drinking water, animal and human-sources*

4. Seroprevalence studies of different British Columbia populations**

5. Development of improved methods for cyst detection in drinking waters***

Funding support also provided from: *B.C. Health Care Research Foundation, **Vancouver Foundation, ***National Reference Centre for Parasitology, and ****Health and Welfare Canada.

Contact: Dr. Judy Isaac-Renton (p): 875-4432
(f): 875-4865